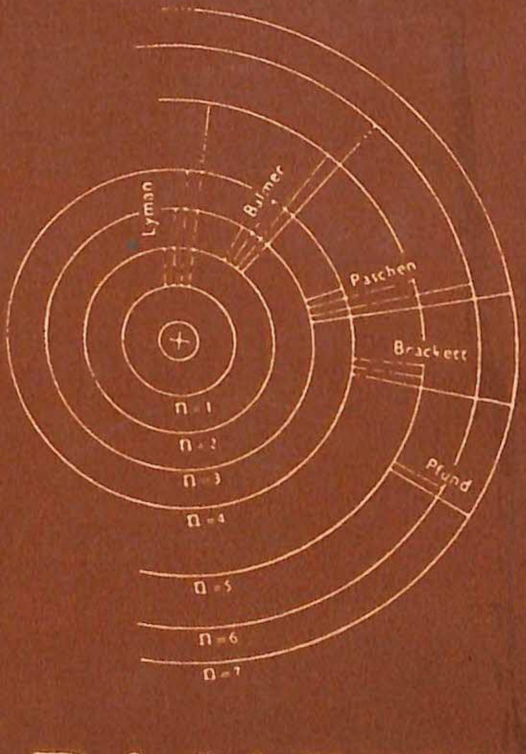
A programmed course in
MODERN PHYSICS



RAJARSHI BHATTACHARJEE

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A PROGRAMMED COURSE IN MODERN PHYSICS

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Rajarshi Bhattacharjee

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PREFACE

This undertaking is an outgrowth of the teaching of Modern Physics to Degree and Pre-University (+2 level) students. In course of his various assignments as teacher, instructor and examiner, both here and abroad, the author has found certain recurring conceptual difficulties quite disparate with the mathematical sophistication of the students. They find difficulty in accepting the new ideas of the scientific revolution, which commenced around 1895 and form the present-day subject of Modern Physics. To a great extent this is due to—

(i) traditional presentation of physics at school and college levels due to which wrong notions regarding continuity between classical and modern physics are framed ;

(ii) the teacher's difficulties in reducing the new concepts to familiar ones and, at times, total failure to find analogies which could help the students grasp these ideas.

To overcome these difficulties the author has designed a set of programmed instructions for each topic representing a modern concept. Further, the chapters in the book have been arranged in a sequence which should help in the development of awareness about interdependence of different concepts and also their link with the past. The instructional programmes have been presented in a linear form in which concepts and information are gradually introduced and elaborated, ensuring the reader's attention at each step by requiring a response.

It is, indeed, a pleasure to acknowledge the guidance of Dr. B. D. Nag Choudhury, ex-Vice Chancellor of Jawaharlal Nehru University, New Dehli, and Prof. M. K. Das Gupta of Calcutta University, in designing the book. Thanks are also due to Prof. K. M. Pathak, Head of the Deptt. of Physics, Gauhati University, for going through the entire manuscript and reviewing the same in detail, and then recommending it for publication. Last but not the least, thanks are due to my students for their enthusiasm and inspiration. Many fine texts have undoubtably influenced the author as student and teacher of the subject. Among these I specially acknowledge the work of Anderson, Kaplan, Gladstone, Saha and Srivastava, Rajam, Yavorsky and Pinsky. I express my gratitude to Naya Prokash for agreeing to publish the book in a neat and presentable form. Last of all, I express my indebtedness to late Dr. H. K. Baruah, ex-Vice Chancellor of Gauhati University, to whom I dedicate this book.

Dated, Calcutta
August 15, 1988

Rajarshi Bhattacharjee

A few words about the design of the book

Every reader should go through the following for making the best use of the book.

It is common practice over the centuries for teachers to stand in front of classrooms and dispense words of wisdom. Students pass or fail depending on how much of this knowledge they can recall at the time of examination. This form of instruction has obvious limitations. Transfer of knowledge is rather poor in traditional lecture method. Tutorial arrangement, an improvement over the traditional method, is a costly proposition on a large-scale basis requiring one-to-one relationship between the student and teacher. In 1950s under the guidance of B. F. Skinner of Harvard University, a celebrated name in Psychology, an effort was made to approximate some aspects of tutorial instruction in the form of a Teaching Machine. In developed countries Computer Assisted Instructions (CAI), which are developed forms of teaching machines, are presently being used for the benefit of students. CAI or Teaching Machines are very costly propositions under the existing techno-economic conditions of India. Instructional Programmes may prove better suited to the country's need.

The essence of teaching, whether in classroom or under computer control, lies in the arrangement of the material to be learned. A body of materials arranged so as to be most readily mastered is called a programmed course. Instructional programmes are generally presented in linear form. In this book attempts have been made to represent the concepts and information of Modern Physics in Linear Programmes in which new information is gradually introduced and elaborated. The reader is advised here to cover the space on the right hand side of every page where correct responses are given, with a scale or paper, and consult only when he has made up his mind about the correct response. This will ensure his full attention at each step. The entire text is to be read following this procedure.

The book has ten chapters representing the evolutionary trend in Modern Physics. The chapters are :

I. Planck's Quantum of Energy
II. Photoelectric Emission
III. Compton Effect
IV. Matter Wave
V. Rutherford's Atomic Model
VI. Atomic Spectra
VII. Bohr's Theory of Hydrogen Atom
VIII. Introduction to Quantum Mechanics and Schrodinger Equation
IX. Radioactivity
X. Artificial Transmutation

These cover the entire course of Modern Physics as taught in the Higher Secondary and Degree classes throughout the country. The book will be very helpful as supplementary to textbook reading.

Rajarshi Bhattacharjee

CONTENTS

Errata

	Incorrect	*Correct*
Page 3 : Statement No. 8	10 m^2	10^{-5} m^2
Page 26 : Statement No. 39	$\nu_0 = 1972$ ÅU	$\lambda_0 = 1972$ ÅU
Page 43 : Statement No. 19	$\lambda_n = 0{\cdot}286$ Å	This should be placed under Correct Response
Page 53 : Soln.	2×10^{23}	2×10^{-23}
Page 61 : Line 2, Statement No. 33	(can/cannot) explained	(can/cannot) be explained
Page 71 : Statement No. 16	$R = 3,\ 29 \times 10^{15}$	$R = 3{\cdot}29 \times 10^{15}$
Page 78 : Line 8	through	thorough
Page 93 : Statement No. 4 (in Correct Response)	The reader advised	The reader is advised
Page 97 : Statement No. 15	$K = \frac{1}{2} mV^2$ $\frac{1}{2} mV^2 = (E - V)$	$K = \frac{1}{2} mv^2$ $\frac{1}{2} mv^2 = (E - V)$
Page 99 : Line 5	drak	dark
Page 100 : Line 7	nucleus	nuclei
Page 107 : Statement No. 41	member one of	member of one of
Page 110 : Statement No. 56	enitting	emitting
Page 114 : Statement No. 73	closes	close
Page 115 : Statement No. 80 (in Correct Response)	$4 \times 5{\cdot}6$ MeV $= 22$ MeV	$4 \times 5{\cdot}6$ MeV $= 22{\cdot}4$ MeV
Page 123 : Statement No. 6 (in Correct Response)	$[_{18}Al^{36}]_{17}Cl^{35}$	$[_{18}A^{36}]_{17}Cl^{35}$

The following word / words should be omitted

Page 53 : Soln. (in Correct Response)	one
Page 99 : Line 10	rays
Page 108 : Statement No. 46	(Jashed)

I

Planck's Quantum of Energy

The how and why of 'black-body radiation' occupies important position in the development of modern physics. A black surface is known to be efficient than any other coloured surface in absorbing radiation. Over the years a theoretical concept of black body developed to represent a perfect absorber as also an emitter of radiation. Although no such black body can be devised, for practical purposes close approximation is possible.

Scientists used black body to measure the amount of energy radiated by it at various wavelengths when hot. Radiation emitted from a hot body is known as thermal radiation. It is a function of the temperature (T) of the black body. When dispersed by a prism, the thermal radiation forms a continuous spectrum. It was observed (in the later part of the nineteenth century) that in such a spectrum the energy emission is not the same for all wavelengths, but has a maximum value at a particular wavelength, which is inversely proportional to the absolute temperature (T) (Wien's law). The total energy emitted per unit time by the hot black body was also observed then to vary as the fourth power of T (Stefan-Boltzmann law).

W. Wien of Germany (1896) and Lord Rayleigh of England (1900) tried to explain the behaviour of black bodies at different temperatures. The equation derived by Wien was found to be valid only at lower temperature for short wavelength radiations. Rayleigh's equation, on the other hand, was applicable only at high temperatures for long wavelengths. Both of these equations were developed from Maxwell's concept about the relationship between electromagnetic waves and radiation. At that time Maxwellian ideas appeared pretty sound, being in agreement with wave theory of light. However, an all comprehensive theory capable of explaining black-body radiation remained elusive.

The dilemma was finally resolved by Max Planck of Germany sometime around 1900. Instead of modifying Wien or Rayleigh he introduced a revolutionary idea. Earlier scientists had regarded the black body as consisting of a system of vibrators oscillating at a particular frequency corresponding to that of the absorbed or emitted radiation. The radiation, which had been assumed as wave like in nature, was considered to be absorbed or emitted in a continuous manner. Planck accepted the general concept of oscillators (also known as resonators) but discarded the concept of continuous emission or absorption of radiation energy. There he departed from the then prevailing concept of radiations, referred to as classical concept. He proposed that a body emits or absorbs

energy in integral multiples of a definite amount, or quantum, whose magnitude depends on the vibrational frequency of the oscillators. Originally, Planck named those definite quantities of energy as 'energy elements'. The term 'energy quantum' was later introduced by Einstein in 1905. According to Planck, a body can emit or absorb one, two, three, etc., quanta of energy but no intermediate or fractional amounts. This statement forms the basis of Quantum Theory of Radiation which holds its sway over modern physics.

The quantum of energy E for radiation of frequency ν is given by the simple but fundamental expression :

$$E = h\nu$$

Where h is a universal constant, called the Planck's constant after the name of the proposer of this new concept.

The magnitude of the constant h is one of the fundamental constants of nature like charge of an electron or the velocity of light. Its accepted value is $6{\cdot}63 \times 10^{-34}$ Joule sec.

STATEMENTS	CORRECT RESPONSE
1. From spectroscopy we know that a 'black body' is a surface which reflects none of the electromagnetic radiation which falls on it. Any surface, which reflects none of the radiation which falls on it, absorbs (all/some/none) of the radiation.	all
2. A physical structure which absorbs all of the radiation incident upon it (is/is not) a black body.	is
3. The radiation emitted by a body as a result of its temperature is called thermal radiation. All bodies emit such radiation to their surroundings and absorb such radiation from them. If a body is at first hotter than its surroundings it will cool off because its rate of emitting energy exceeds its rate of absorbing energy. When thermal equilibrium is reached, the rates of emission and absorption are equal. Emissivity of a surface is equal to its absorptivity. A physical structure which reflects none of the radiation incident on it (is/is not) a surface with maximum emittance.	is
4. Drill a hole or cavity into a hollow cylinder made of a high melting point substance like tungsten or platinum. The cavity is empty space ; it reflects (all/some/none) of the radiation which falls on it.	none
5. If the cavity is considered a 'surface', it absorbs all the incident radiation on it and reflects none. The (cavity/the cylinder) is a black body.	cavity

STATEMENTS **CORRECT RESPONSE**

6. At temperature when the tungsten cylinder (refer to Fig. 1·1) does not emit visible electromagnetic radiation but is seen by reflected light, the cavity in its wall is (brighter/darker) than the rest of the cylinder. Why ?

darker. The cavity is the black body and does not reflect light.

7. When the above cylinder is placed in a dark room, it can only be seen by the light it emits. If the cylinder is now heated until it is hot enough to glow (Fig. 1·1), the cavity is (brighter/less bright) than the rest because (the surface of the cylinder/cavity) is the better emitter of radiation.

brighter
cavity

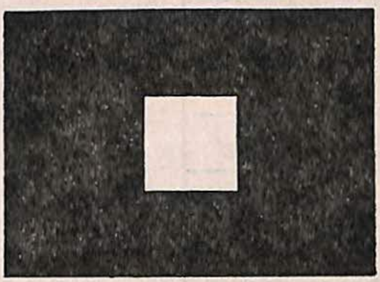


Fig. 1·1. Hollow Tungsten Cylinder with a small hole drilled on its side, when incandescent. The light used to take a picture like this will be the light emitted by the cylinder.

8. Radiations emitted by different surfaces and cavities are compared in terms of their intensities. Intensity is the amount of energy which leaves the radiating surface or cavity per unit area of the radiator in a second. If 20 joules of energy is emitted from a cavity which has an area of 10 m^2 in 40 sec., then the intensity of this radiation is ——.

5×10^4 $J/m^2/sec$

9. When the cavity is darker than the rest of the cylinder surface, the intensity of radiation from it is (greater/less) than the rest of the cylinder. When the cavity is (brighter/darker) than the rest of the cylinder, the intensity of radiation from the cavity is greater than that from the rest of the cylinder.

less
brighter

10. Infrared waves are responsible for most of the heat transfered by radiation. Fig. 1·2 is a classification of electromagnetic waves according to frequency and wavelength. It is obvious that infrared waves (are/are

STATEMENTS	CORRECT RESPONSE
not) visible. Comparison of radiation from different surfaces in terms of 'darker' and 'brighter' is meaningful only when the emitted electromagnetic waves are	are not
visible. Hence it (is/is not) possible to compare the intensities of infrared radiations from different surfaces in terms of 'darker' and 'brighter'.	is not

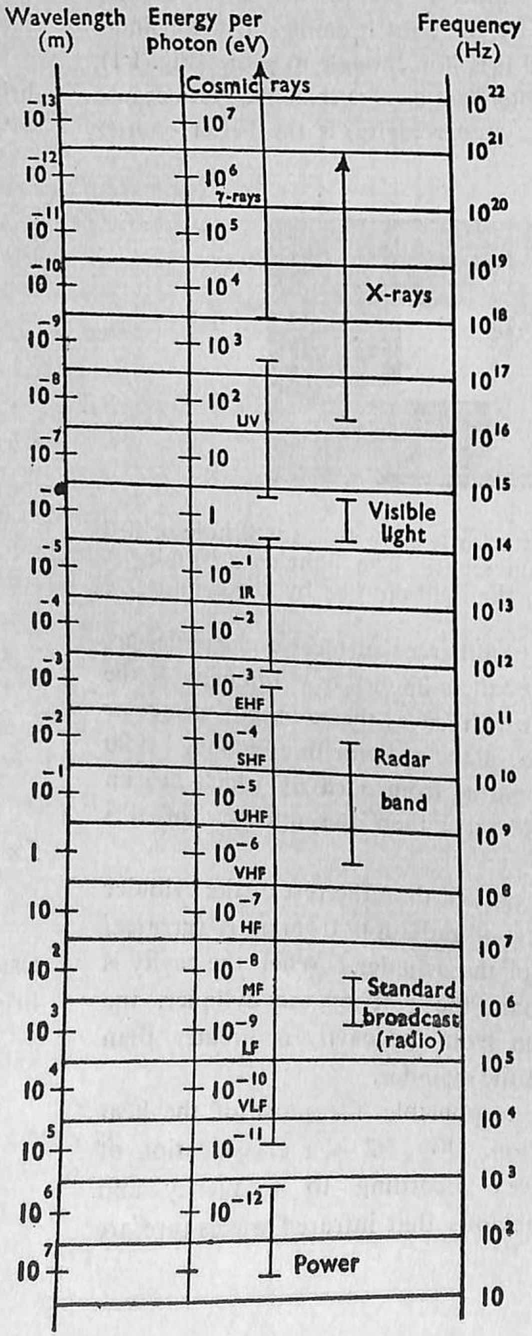


Fig. 1·2. The Electromagnetic Spectrum showing Wavelength, Frequency and Energy per photon on a logarithmic scale. Readers studying Chapter I may overlook the Energy per photon scale.

STATEMENTS	CORRECT RESPONSE
11. Energy leaving a surface in the form of infrared waves can be measured by using special techniques. We (can/cannot), therefore, compare the intensities of radiation from different surfaces when they are not in the form of visible light.	can
12. A cavity radiator reflects none of the visible light which falls on it ; it reflects (all/some/none) of the infrared waves which falls on it. A cavity radiator (is/is not) a black body for infrared radiation.	none is
13. A cavity radiator (a hollow tungsten cylinder with a cavity) emits a continuous spectrum of radiation when heated. The detail of the spectrum are almost independent of the particular material with which the body is composed, but depend strongly on temperature. When heated, infrared waves can be detected before one is aware of visible light. At this point the intensity of radiation from the cylinder wall is (less/greater) than that from the cavity.	less
14. Small equal sized holes are drilled in two hollow cylinders, one made of tungsten and the other of platinum. Both are heated to the same temperature and measurements are made of the intensity of radiation from the cavities. The intensity of the emitted radiation from the cavity in platinum is (greater than/less than/equal to) that from the cavity in the tungsten cylinder.	equal to
15. Since the intensity of radiation from a black body depends on its temperature, we can expect the intensity of radiation from a cavity radiator to (increase/decrease/remain unchanged) as its temperature increases. From cavities in different substances at the same temperature we expect (different intensities/the same intensity) of radiation.	increase the same intensity
16. Different measurements of the intensity of radiation from the same cavity show that we can detect infrared radiation at a lower temperature than we can detect visible radiation. The frequency of visible light is (greater than/less than/equal to) the frequency of infrared radiation. Hence, when the temperature of the cavity radiator increases the frequency of the radiation emitted with maximum intensity tends to (increase/decrease/remain constant).	greater than increase

STATEMENTS	CORRECT RESPONSE
17. Examine Fig. 1·3 ν_{max} on each curve represents the particular frequency which is radiated at maximum intensity at the temperature indicated. At 10000 °K the frequency which is radiated at maximum intensity is in the (infrared/visible/ultra-violet) part of the spectrum.	visible
The frequency radiated at maximum intensity at room temperature (about 27 °C or 300 °K) has an order of magnitude ($10^{12}/10^{13}/10^{14}$) Hz (c.p.s.).	10^{13} Hz
As the temperature of a cavity radiator increases, the frequency of the wave radiated at maximum intensity shifts in this diagram to the (left/right).	right
18. Fig. 1·3. To obtain a frequency of maximum intensity in the ultra-violet part of the spectrum, the temperature of the cavity radiator must be (greater than/less than) 10000 °K.	greater than
19. From our idea of waves we know that the frequency and the wavelength of a wave are inversely proportional to each other. This means that the wavelength of infrared radiation is (longer than/shorter than/equal to) the wavelength of visible light waves.	longer than

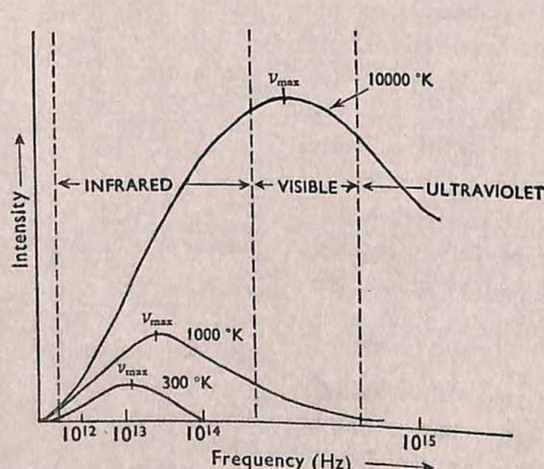


Fig. 1·3. This is a plot of intensity of cavity radiation against frequency of emitted radiation. Three different curves for three different temperatures are shown. To bring out the qualitative aspects of the relationship some distortions have been resorted to. (Figure taken from Physics, K. R. Atkins, John Wiley and Sons.)

STATEMENTS	CORRECT RESPONSE
20. Fig. 1·4 is a plot of intensity of radiation from a cavity radiator at a specific temperature against the wavelengths of the electromagnetic waves emitted. The black circles represent actual experimental values. The solid curved line and the dashed line are graphs of equations formulated to predict experimental values. On the left, the curves corresponding to Wien's equation and Planck's equation coincide and both fit experimental data (well/badly) for shorter wavelengths or higher frequencies. For wavelengths greater than 3×10^{-6} m (1. neither fits the experimental data/ 2. Wien's law fits the experimental data better than Planck's law / 3. Planck's law is a better fit to the experimental data than Wien's/ 4. both fit experimental data equally well).	well 3
21. (Wien's/Planck's) equation is consistent over the entire range of experimental data shown in Fig. 1·4.	Planck's

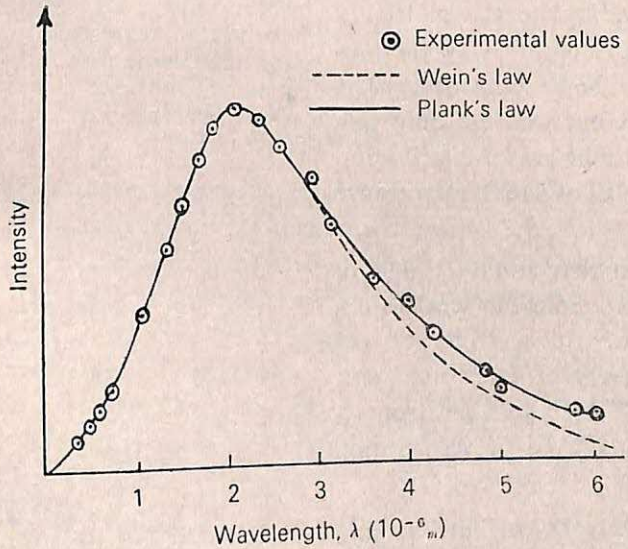


Fig. 1·4. This is a plot of intensity of radiation from a cavity radiator at a specific temperature against the wavelength of the electromagnetic waves emitted.

On the short wavelength side predictions from Wien's and Planck's equations agree very well with experimental findings.

On the high wavelength side Wien's equation fails to predict experimental observations. Planck's equation is observed to be consistent over the entire range of the experimental data.

STATEMENTS	CORRECT RESPONSE

22. When Planck began his investigation, the quantum theory of radiation was unknown (in fact it was Planck's investigation on black-body radiation which led to its formulation). In radiation problem at that time, even the notion of temperature could be introduced only by considering the energy exchanges between matter and radiation. Planck imagined that a black radiation chamber was filled up not only with radiation but also with the molecules of a perfect gas. At that time the exact mechanism of generation of light by atomic vibrations or absorption of light by atoms or molecules was unknown and so radiation and gas molecules of the classical kinetic theory could not be assumed to exchange energy directly. Planck, therefore, introduced resonators of molecular dimensions as the via media between radiation and gas molecules. These resonators absorbed energy from the radiation and transferred energy, partly or wholly, to the molecules when they collided with them. In that way thermodynamical equilibrium could be established. The process was rather round about but was the only one possible then. Besides leading to the law of distribution of energy, it yeilded other results of great importance in physics.

    At that time it was known that certain kinds of electromagnetic radiation resulted from the acceleration of electrically charged particles ; it was one of the assumptions of the classical theory of electromagnetic radiation (formulated around 1870) that all electromagnetic radiation resulted from some kind of acceleration of electric charges.

    Radio waves result when electrons oscillate up and down an antenna in simple harmonic motion, a form of accelerated motion. The production of radio waves (is/is not) consistent with classical theory. — is

23. The resonators introduced by Planck were dipole oscillators (Hertzian type) of molecular dimension. Refer to Fig. 1·5. The concept of dipole oscillator (is/is not) consistent with classical theory of electromagnetic radiation. — is

STATEMENTS **CORRECT RESPONSE**

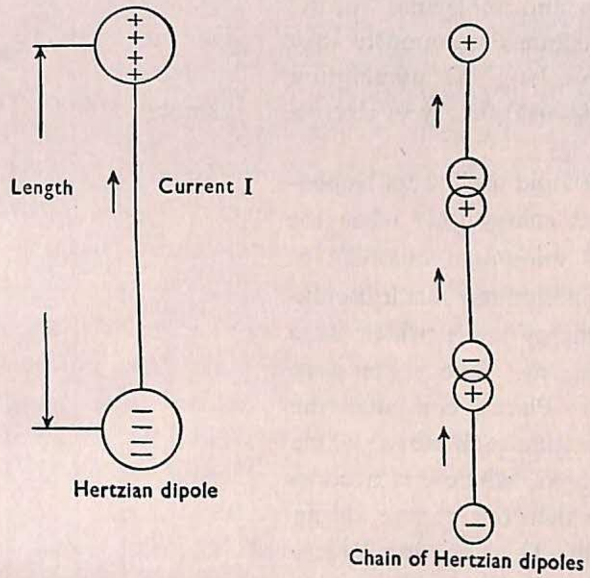


Fig. 1·5. The concept of the Electric Dipole is extremely helpful in Electromagnetic field theory. Two equal and opposite charges of magnitude q separated by an infinitesimal distance dl are said to constitute an electric dipole (also called electric doublet).

24. Most physicists agreed that the cavity radiation (shown in Fig. 1·4) could be explained in terms of oscillation of charges in microscopic 'antenna' or oscillators (probably atoms and molecules) in the walls around the cavity. It is known that the atoms and molecules in the walls around the cavity are in a state of continuous oscillation ; this means that the charges in them are (always /sometimes/never) accelerating and that each microscopic oscillator should radiate energy (continuously/in spurts).
   always
   continuously
25. In the formulation of his equation, Wien made the classical assumption that the microscopic oscillators in the walls around the cavity emit radiation continuously. Refer to Fig. 1·4. It shows that the classical theory proposed by him (did/did not) agree with all the experimental observations.
   did not
26. As the theory of continuous emission of radiation did not yield a formula consistent with experimental data, Planck abandoned the hypothesis. He proposed that

STATEMENTS	CORRECT RESPONSE
although charges in the atoms and molecules in the walls surrounding a cavity oscillate continuously they do not emit radiation continuously. This assumption (is/is not) consistent with the classical theory of electromagnetic radiation.	is not
27. Planck assumed that the microscopic oscillators responsible for cavity radiation emit energy only when the energy absorbed is a certain minimum quantity or some integral multiple of this minimum. Such oscillators could, therefore, exist in energy states which were allowable without radiating energy. The states were called allowable energy states; Planck computed the allowable energy states of a vibrating oscillator as whole number multiples of the quantity $h\nu$, where h is a constant and ν the frequency at which the charge in an oscillator moves back and forth. The equation $E=nh\nu$ describes an allowable energy state if n is (any whole number/any fraction).	any whole number
28. Planck's another assumption was that when an oscillator is in any one of its allowable energy states, it neither emits nor absorbs energy. In an allowable energy state, the charge in an oscillator (continues/ceases) to accelerate; the oscillator (radiates/does not radiate) energy.	continues does not radiate
29. $E=nh\nu$. The value of h is $6{\cdot}63\times10^{-34}$ joule sec., when E is in Joule and ν in cycles per second. The product $h\nu$ is called a quantum of energy and n is called the quantum number.	
The quantum of energy associated with an oscillator which has a frequency of 10^{13} c.p.s. is —— . When the oscillator exists in an allowable energy state with a quantum no. 2, its energy is —— joule.	$6{\cdot}63\times10^{-21}$ J $1{\cdot}33\times10^{-20}$
30. $E=nh\nu$. This equation describes an allowable —— —— when n is a —— ——. Can the oscillator, described in item 29 above, exist with an energy of 3×10^{-21} J? (Yes/No). Explain.	energy state quantum number No. It represents a fractional quantum no. which is not permissible
31. When a cavity oscillator exists in an allowable energy state it (continues to emit/does not emit) radiation and it (absorbs/does not absorb) energy.	does not emit does not absorb

STATEMENTS	CORRECT RESPONSE
32. An oscillator cannot possess any amount of energy; it can only have energies specified by the expression $nh\nu$, where ν is the —— of vibration of the charge associated with the oscillator. The product $h\nu$ is called a —— of energy of this particular oscillator. n can take on (any fractional number/only integral number/either fractional or integral number) values.	frequency quantum only integral number
33. Planck's final assumption was that an oscillator responsible for cavity radiation actually emitted an electromagnetic wave only when it changes from one allowable energy state to another with a lower quantum number. Assuming an oscillator vibrating with a frequency of 10^{12} c.p.s. and existing in an energy state represented by quantum no. 3, we can compute its energy in this particular state as —— joule. The electromagnetic wave this oscillator emits while in this energy state carries an energy of —— J. Will this oscillator emit radiation as it changes to an allowable energy level with quantum no. 2? (Yes/No). Will it emit radiation as it changes to an allowable energy level with quantum no. 4? (Yes/No).	2×10^{-21} zero Yes No
34. According to classical theory, the electromagnetic waves emitted by an oscillator vibrating at a frequency ν should be (continuous/discontinuous). According to Planck's assumption these waves are emitted only when the oscillator changes from one energy state to another with a (lower/higher) quantum number and they should, therefore, be (continuous/discontinuous).	continuous lower discontinuous
35. Let us derive an expression relating energy emitted and the jump, called quantum jump, involved. When an oscillator changes from one energy state (E_2) to another (E_1) with a lower quantum number, emission of eloctromagnetic radiation is (allowed/not allowed). Let $E_2 = n_2 h\nu$ and $E_1 = n_1 h\nu$. The energy emitted when this transition occurs is: $E_2 - E_1 =$ —— (use symbols)	allowed $(n_2 - n_1)\ h\nu$
36. In the equation in item 35, n_2 and n_1 are both whole numbers and $n_2 > n_1$; the quantity $(n_2 - n_1)$ (is/is not) a whole number and has a minimum value of —— (number).	is 1

STATEMENTS	CORRECT RESPONSE
37. Suppose an oscillator has a frequency of 10^{14} c.p.s. and exists in the 5th quantum state. For it n is equal to (4·5/5/6). The energy of the oscillator while it is in this state is —— J. The electromagnetic energy it emits while it is in this state is —— J.	5 $3{\cdot}315\times10^{-19}$ zero
38. Suppose an oscillator is vibrating at a frequency of 10^{11} Hz. Its quantum energy is —— J in the third quantum state. Under any possible transition to another state, can it emit radiant energy of $2{\cdot}21\times10^{-23}$ J ? (Yes/No). Explain.	$1{\cdot}99\times10^{-22}$ No; because this energy is less than one quantum of energy of the oscillator
39. According to Planck the energy emitted by an oscillator in any transition from one energy state to another with a lower quantum number (can/cannot) be less than one quantum. Could the oscillator in item 38 emit radiation of $11{\cdot}2\times10^{-23}$ J ? (Yes/No). Explain.	cannot No ; the given energy is not an integral multiple of one quantum of energy
40. The oscillator described in item 37 undergoes a quantum jump to the allowable energy state in which $n=3$. Compute the energy emitted in the transition.	$1{\cdot}326\times10^{-19}$ J
41. Refer to item 38. The energy emitted while the oscillator is in an allowable energy state with quantum number $n=3$ is —— joule. The minimum amount of energy this oscillator can emit in a transition from one energy state to another with a (lower/higher) number is —— J or one ——.	zero lower $6{\cdot}63\times10^{-23}$ J; quantum
42. Planck's assumption that the radiation from an individual oscillator in walls around a cavity is emitted in spurts, lead to the idea of energy quantisation in physics for the first time. When we say that energy is quantised we mean that there is a certain (minimum /maximum) quantity of energy which is known as a —— of energy.	minimum ; quantum
43. According to classical theory, radiation from an oscillator in the walls around a cavity radiator is emitted (continuously/in descrete amounts). The theory assumes that the energy (is/is not) quantised.	continuously is not
44. Planck's assumption about radiation emitted by microscopic oscillators in the walls of a cavity radiator	

STATEMENTS	CORRECT RESPONSE
constitutes the first step in the development of quantum theory. He assumed that an oscillator emits or absorbs energy (continuously/in descrete amounts) and only ((1) when it is in an allowable energy state/(2) when it is changing from one allowable state to other.).	in discrete amounts (2)
45. Planck's assumption is that an oscillator absorbs radiant energy only when it jumps from one allowable energy level to another with a (higher/lower) quantum number. It emits radiation only when it changes from one allowable energy level to another with a (higher/lower) quantum number. Because the energy absorbed or emitted by a cavity oscillator is a whole number multiple of a certain minimum amount called quantum of energy, and the energy is said to be —— .	higher lower quantised
46. Planck's theory of cavity radiation is based on two assumptions regarding the microscopic oscillators in the walls of the cavity. Choose the correct statements from the following : (i) A cavity oscillator emits radiant energy continuously because it contains electrically charged particles which are in a state of continuous vibration. (ii) A cavity oscillator can exist in any energy state which is a fractional multiple of its quantum energy. (iii) A cavity oscillator can exist in any energy state independent of its frequency of oscillation. (iv) A cavity oscillator can exist only in energy states which are integral multiples of its quantum energy. (v) An oscillator emits or absorbs radiant energy only when it changes from one energy level to another.	(iv) & (v)
47. Imagine a cavity oscillator vibrating with a frequency of 3×10^{14} Hz in an energy state with quantum no. 2. While in this state it emits radiant energy of —— joule and absorbs radiant energy of —— joule. The energy it must absorb to bring to the energy state with quantum no. 4 is —— joule. Can it absorb radiant energy of $6 \cdot 63 \times 10^{-20}$ J ? (Yes/No). Explain.	zero zero $3 \cdot 98 \times 10^{-19}$ No, because the amount is less than one quantum of oscillator energy

STATEMENTS	CORRECT RESPONSE
Note :	
(a) Like energy quantisation, we are familiar with another type of quantisation known as charge quantisation. From our study of electricity we recall that there is a minimum amount of electric charge ($=1{\cdot}6\times10^{-19}$ coulomb) which represents the magnitude of the charge on a single electron. In as much as electric charge is a whole number multiple of this minimum, it (is/is not) quantised.	is
(b) The constant h, known as Planck's constant, has the value $6{\cdot}63\times10^{-34}$ joule sec. Along with the velocity of light in vacuum and the charge of an electron, it represents three fundamental constants in modern physics. The student is advised to memorise the values of all these constants.	
(c) $e=1{\cdot}6\times10^{-19}$ coulomb represents (the charge of an electron/velocity of light in vacuum).	the charge of an electron
$c=3{\cdot}0\times10^{8}$ m/sec represents (Planck's constant/velocity of light in vacuum).	velocity of light in vacuum
$h=6{\cdot}63\times10^{-34}$ joule sec, and is known as (electronic charge/Planck's constant).	Planck's constant
(d) At what wavelength does a cavity radiator at 6000°K radiate most ? Assume that the Wien's constant has the value 0·3 cm °K.	$\lambda_m T=0{\cdot}3$ $\therefore\ \lambda_m=5000$ ÅU
(e) At what wavelength does the human body emits radiation ? What assumption should you make ?	99774 ÅU Here we assume that human body is a black-body at a temperature of 37 °C, i.e., 310°K. The wavelength lies in the far infrared region of the e.m. spectrum.

II

Photoelectric Emission

In 1873 W. Smith, a telegraph operator, was measuring the resistance of trans-Atlantic cables using an apparatus which had selenium resistors in it. To his surprise he observed that when sunlight was incident on those resistors the current in the circuit varied considerably. This incident is on record as the first ever observation of generation of electricity by light.

In 1887 Hertz, inventor of wireless communication, noticed that ultraviolet light falling on the electrodes of a spark gap caused the sparks to jump greater distances than when the gap was not exposed to ultraviolet light. In 1888 Hallwachs placed two zinc plates in an evacuated quartz tube, and connected one of the plates to the positive end of a battery and the other to the negative end. By shining ultraviolet light on the negative plate he observed that a current would begin to flow in the circuit immediately. However, it stopped as soon as the ultraviolet was withdrawn. Hallwachs further observed that except when the battery voltage was low, no current would flow in the circuit if the light beam was made to fall on the positive plate.

Although the term 'Photoelectric Effect' was coined to describe the phenomenon, no immediate explanation was forthcoming as to its cause. Only after J. J. Thomson had discovered the existence of the electron, Lenard (around 1900) could prove that the above effects were due to the emission of electrons from the metallic surfaces exposed to light. It was Einstein (1905) who first gave a sound theoretical explanation of the nature and cause of such occurrences. The phenomenon of emission of electrons from the surface of a good number of substances, mainly metals, under the action of electromagnetic radiations, which include even X-rays and γ-rays, is now known as photoelectric emission and the current so produced (i.e., the no. of electrons emitted per unit time) called photocurrent.

STATEMENTS	CORRECT RESPONSE
1. Recall your ideas about electromagnetic radiations. The ultraviolet radiation has (higher/lower) frequency than the visible light.	higher

STATEMENTS	CORRECT RESPONSE
2. Hallwachs' observation could be explained as due to the emission of (electrons/electromagnetic radiation) from the surface of the electrode due to the action of the ultraviolet light.	electrons
3. It has been observed that alkali metals, i.e., lithium, sodium, potassium and cesium show remarkable photoelectric effect even with visible light. All substances exhibit photoelectric effect when they are illuminated by X-rays and γ-rays. X-rays and γ-rays are —— frequency electromagnetic radiations.	high
4. Fig. 2·1 is the plan of an experiment to study photoelectric phenomenon. Plate *A* there is the cathode; it is coated with —— metal to make it photo-sensitive.	alkali
Along with the anode *B* which is specially designed, it is placed inside a glass envelope which is evacuated. There is a quartz window in the front through which light of any desired frequency can be made to shine on *A*. *PQ* is a voltage divider and *G* a sensitive galvanometer to measure —— current in the circuit.	photoelectric
The battery is connected to the circuit via a polarity reversing switch. This enables the experimenter to make *A* positive with respect to *B* when required. When the plate *A* is negative with respect to *B* we call the applied potential accelerating because it helps emission of —— from *A*.	electrons
When *A* is positive with respect to *B* we call the applied potential retarding because emitted electrons are (attracted/repelled) electrostatically by the positive field of the electrode *A* and (attracted/repelled) electrostatically by the negative field of the electrode *B*.	attracted repelled
This (reduces/increases) the flow of —— current in the circuit.	reduces ; photoelectric
5. Refer to Fig. 2·1. Current in the circuit is measured by the galvanometer. Keeping the intensity of the incident light constant, the increase in circuit current due to various accelerating potentials applied between the electrodes *A* and *B*, is measured. Reversing the potential and thereby making the field retarding, the current in the circuit can be made to (increase/decrease).	decrease
If the intensity of the incident light is altered the strength of the photo-current (changes/remains the same).	changes

STATEMENTS | CORRECT RESPONSE

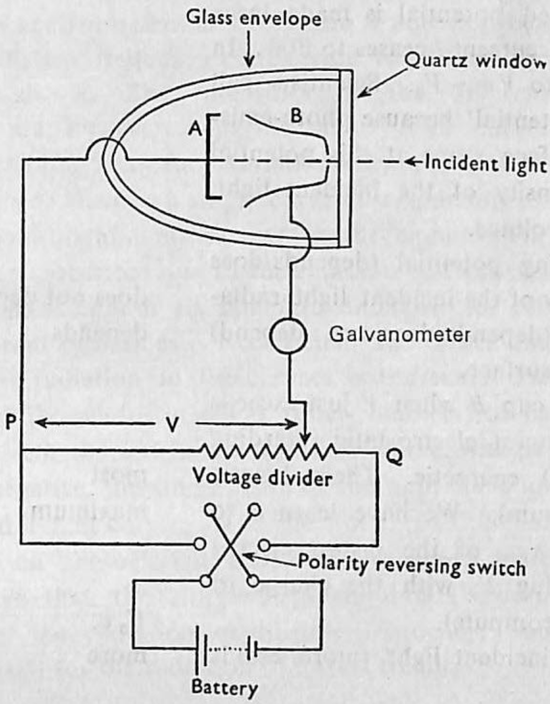


Fig. 2.1

6. Fig. 2.2 is a plot of photo-current, i, in the circuit against the applied potential V, between A and B for two different intensities of the incident light. Curves (a) and (b) are drawn for the light of (same/different) intensities. They show the same pattern of rise with voltage though current in (a) is more than that in (b). In both the curves, the photocurrent (rises/does not rise) vertically to its maximum. The maximum current is also called saturation current. When V is made large enough, the photo-current (reaches/does not reach) saturation limit. At this point all the photo-electrons ejected from A reach B. — different; does not rises; reaches

7. For both the intensities, when V=0 the current i (is/is not) zero. When V is reversed in sign and made (accelerating/retarding), the current i (does/does not) immediately drop to zero. This suggests that the electrons are emitted from A with some kinetic energy. So, some of these photoelectrons will reach the cup B in spite of the fact that the electric field opposes their — is not; retarding ; does not

STATEMENTS	CORRECT RESPONSE
motion. When the reversed potential is made large enough, i.e., more negative, current i ceases to flow. In Fig. 2.2 this corresponds to $V = -V_0$. Scientists call this potential 'stopping potential' because photo-emission from a particular surface stops at this potential whatever may be the intensity of the incident light. It is also known as cut-off voltage.	
8. Examine Fig. 2.2. Stopping potential (depends/does not depend) on the intensity of the incident light radiation. Stopping potential (depends/does not depend) on the nature of the photo-surface.	does not depend depends
9. Electrons which reach the cup B when V just exceeds $-V_0$, overcoming the strongest electrostatic retarding force, are the (most/least) energetic. Their kinetic energy is (maximum/minimum). We have learned to compute the kinetic energy K_{max} of the fastest ejected photoelectron by multiplying V_0 with the charge of the electron. K_{max} = —— (compute).	most maximum $V_0 . e$.
10. More the intensity of the incident light, (more/less) is the current.	more
11. Two most important properties of any electromagnetic radiation are its frequency and wavelength. They are related by the equation —— (complete). Examine Fig. 2.3. It is another plot of photoelectric current, i,	$\lambda\nu = c$

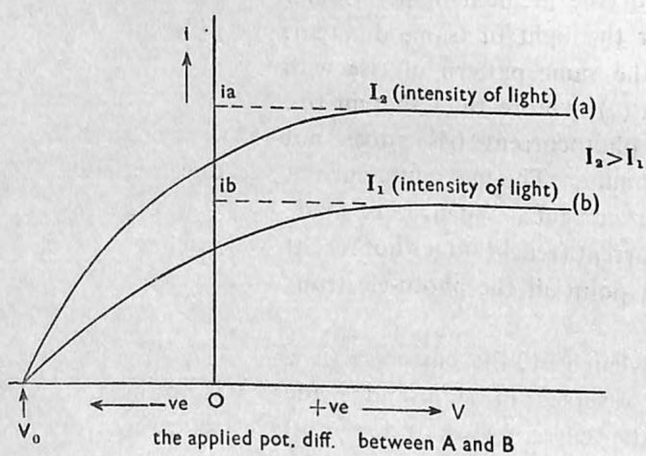
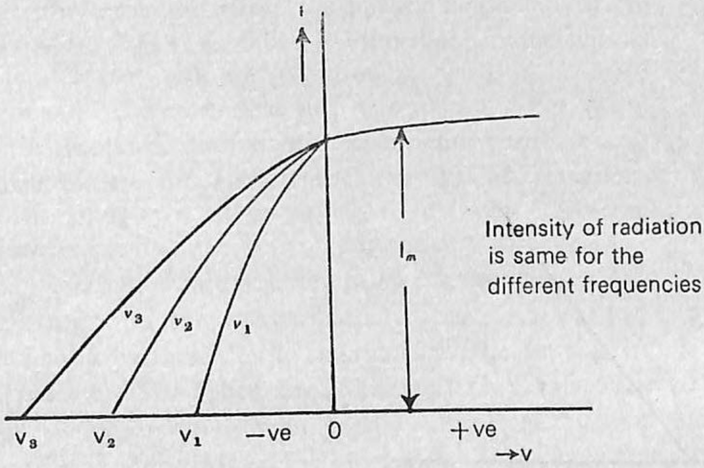


Fig. 2.2

ia = Saturation current for curve (a)
ib = Saturation current for curve (b)

STATEMENTS	CORRECT RESPONSE
against the applied potential V between A and B, when light of different frequencies are made to fall on the photo-cathode A. The intensities of the different radiations are, however, kept the same. Such curves can be called the 'frequency variation curves'. On the right-hand side there is a single curve corresponding to the (maximum/minimum) current in the circuit.	maximum
The photocurrent produced due to the emission of electrons from the photo-cathode (is same/are different) for the three different radiations.	is same
Recall item 10. Since the intensity of radiation in these cases is the same, the strength of the photo-current is (likely/unlikely) to be the same.	likely
On the left-hand side of the curve, when V becomes negative, the single curve of the right splits up into —— different curves.	three
The effect of three different radiations on photoelectric emission is manifest here. We observe that the stopping potential is (highest/lowest) for the radiation of highest frequency, and	highest
(highest/least) for the radiation of lowest frequency.	least

Frequency variation curves.



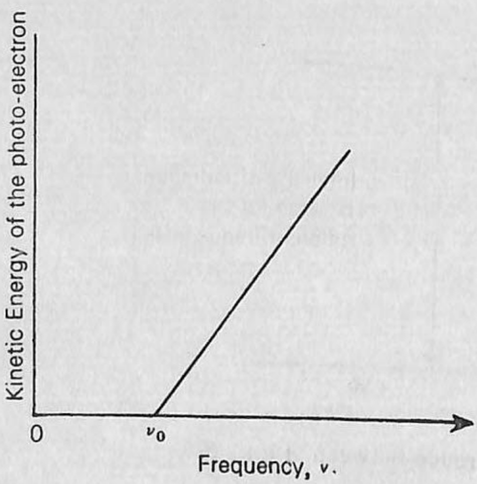
Applied Potential Difference between A and B.

Fig. 2.3

Frequency $\nu_3 >$ Frquency $\nu_2 >$ Frequency ν_1.

I_m = Maximum current in the circuit.

STATEMENTS	CORRECT RESPONSE
12. Refer to the above item 11. When the intensity of the incident radiation is kept constant but frequency varied, the value of the stopping potential (changes/remains the same). Stopping potential (increases/decreases) as the frequency of the incident radiation increases. Increase of stopping potential suggests (increase/decrease) in the energy of the emitted photo-electrons. It is possible to determine the relationship that exists between the frequency of the incident radiation and stopping potential in case of a particular photo-surface by plotting one against the other. Examine fig. 2.4. This is one such plot. It indicates a linear relation between frequency and stopping potential, the latter being the maximum kinetic energy of the emitted photo-electrons. The straight line (does/does not) pass through the origin. It intersects the frequency axis at —— (complete). This suggests that (below/above) the frequency ν_0 no photo-electrons are emitted.	changes; increases; increase; does not; $\nu=\nu_0$; below
13. The above observations form the basis of two important characteristics of photo-electric emission : (I) The no. of electrons emitted from a metal surface depends on the (intensity/frequency) of the incident radiation.	intensity



As $K_{max}=eV_0$, the ordinate may as well represent stopping potential.

Fig. 2.4

STATEMENTS	CORRECT RESPONSE
(II) The energy of the photo-electrons, i.e., their maximum velocity is proportional to the (frequency/intensity) of the incident radiation.	frequency
14. The remarkable feature about emission of photoelectrons from a particular metal is that the energy of the ejected electrons (depends/does not depend) directly on the frequency of the incident radiation. It does not depend on the (frequency/intensity) of the radiation at all.	depends intensity
15. Electron emission from hot metallic surface had been known to the scientists much before photo-electricity was discovered. The phenomenon, which had been named thermo-ionic emission, was found to depend on the temperature of the metallic surface. The thermo-ionic effect is due to the emission of free (also called conduction) electrons from within the metallic surface. Photoelectric effect, as described above, (does/does not) depend on the temperature of the emitting surface. It is (different from/same as) the thermo-ionic effect. The basic mechanism of both the processes (is the same/differ).	does not different from is the same
16. Refer to Item 12. For a given photo-sensitive metal, the photo-electric effect disappears below a certain critical frequency, ν_0, called the threshold frequency. Its value depends on the photo-metal used. Threshold frequency (depends / does not depend) on the intensity of the incident radiation. Physicists define photo-electric threshold as the (frequency/intensity) of radiation, which falling on a photo-surface, is just able to liberate electrons without giving them additional kinetic energy.	does not depend frequency
17. From our study on the nature of electromagnetic radiation, we know that the oscillating electric vector ($\overline{E}$) of the light wave increases in amplitude as the (intensity / frequency) of the light beam is increased. As the force experienced by an electron is charge time the electric vector ($e \cdot \overline{E}$) the kinetic energy of the photo-electron should (increase/decrease) as the incident light beam is made more intense.	intensity increase
18. According to the classical theory of electromagnetic radiation, the photo-electric effect should, therefore, occur at any frequency of the incident light radiation	

STATEMENTS	CORRECT RESPONSE
provided it is intense enough to impart sufficient energy to the ejected photo-electrons. This view, however, is not supported by experimental observations. Classical theory (can/cannot) explain photoelectric emission.	cannot
19. Existence of the threshold frequency, which is a characteristic of every photo sensitive surface, does not allow photo-electric emission to occur below the threshold, no matter how intense may be the illumination. This (agrees/does not agree) with the (classical) wave theory of radiation.	does not agree
20. According to the classical theory, light energy is uniformly distributed over the wave front. Hence, for a feeble source of light there should be a measurable time lag between the time when light is incident on the surface and ejection of photo-electrons. During this interval electrons should be absorbing energy from the beam until they have accumulated enough to escape. However, no detectable time lag has ever been reported.* This disagreement is particularly striking when the photo-electric substance is a gas. Therefore, the mechanism of cummulative absorption of energy (can/cannot) be ruled out. We conclude that the energy of an emitted photo-electron must certainly be soaked out of the light beam by a single atom or molecule.	can
21. Read the problem discussed in panel 1 carefully. The time lag calculated for absorption of the incident ultraviolet radiation and emission of photo-electron is (finite /practically zero). It is of the order of (millisecond /nano-second).	finite millisecond
22. Classical wave theory which assumes that energy is uniformly distributed over the spherical wave fronts spreading out from the source (can/cannot) explain the above contradiction. Classical wave theory (is/is not) adequate to explain the phenomenon of photo-electric emission.	cannot is not

* E. O. Lawrence and J. W. Beams (around 1928) tried to measure the time lag in photo-electric emission. They reported that it should be less than a nanosecond (10^{-9}s).

STATEMENTS	CORRECT RESPONSE
23. Recall your study of black-body radiation (Chapter I). Planck's theory refers to the absorption and emission of radiation. Planck considered only these two processes to have taken place in terms of integral number of energy quanta. The propagation of radiation through space was still regarded as wave motion. We observe that Planck's theory is (able/unable) to explain photoelectric emission.	unable
24. For a satisfactory explanation of the phenomenon, Einstein proposed (1905) that the radiant energy from a source is itself quantised into concentrated bundles called photons. According to Einstein radiation from a source (does/does not) spread out in waves ; radiant energy is shot out in discrete amounts called —— .	does not photons
25. Einstein's photons propagate through space with the speed of light. This bold view, which apparently discarded the wave theory of light in favour of something very much akin to a particle concept, could ultimately provide the successful interpretation of the phenomenon. Einstein's photon theory is reminiscent of an earlier theory of light held by Newton which assumed that a beam of light consisted of (waves /particles).	particles
26. A photon of radiation is one quantum of energy. For frequency (ν) it has a definite magnitude $h\nu$, where h is —— —— . Although the energy carried by a photon is very small, the photons corresponding to light of one frequency (or wavelength) carry the same energy.	Planck's constant
27. Compute the energy of a photon in terms of the wavelenth, λ of the radiation.	$E=h\nu=hc/\lambda$
28. $E=hc/\lambda$. Solar radiation falls on the earth at the rate of 1·94 cal/cm^2 per min. on a surface normal to the incoming rays. Assume an average wavelength of 5500 ÅU for solar radiation. The energy of a solar photon is —— . The total number of photons per cm^2 per min. in solar radiation is —— .	$3{\cdot}6\times10^{-19}$ J $2{\cdot}26\times10^{19}$
29. The quantum of energy associated with radiation of high frequency is greater than that associated with radiation of low frequency. A photon of ultra-violet radiation is (more/less) energetic than that of visible light.	more

STATEMENTS	CORRECT RESPONSE
30. According to Einstein the 'energy packet $h\nu$' is so concentrated that it can transfer its whole energy to an electron in a single collision. When an electron absorbs energy from a radiation, it does so in —— units and not in —— —— .	quantum fraction of a quantum
31. Einstein's photon is a more complicated entity than Newton's corpuscle ; for instance, when we compute the energy of a photon we have to know certain characteristic of the electromagnetic wave associated with it, namely, its —— . However, the interaction of a photon with a material particle like electron in photo-electric emission is characteristic of a (wave/particle) than that of a —— .	frequency (or wavelength) particle wave
32. We know from our study of the atomic structure of the element that the electrons in an atom are ordinarily prevented from leaving the atom and a certain amount of work must be done to enable each electron to escape the energybarrier. Examine Fig. 2.5. This is an energy-level diagram for the conduction (or free) electrons within a metal. It shows that the electrons within the metal exist in energy levels ranging from zero to a maximum energy of —— electron volt. E_B represents	E_M

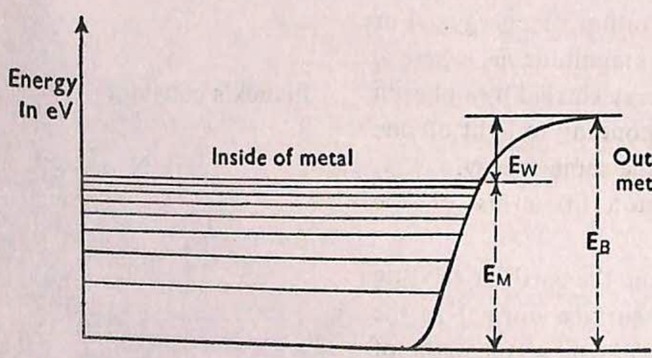


Fig. 2.5

Energy-level diagram for the conduction electrons within a metal.

The potential energy barrier $= E_B$

The maximum energy of an electron inside a metal $= E_M$

Work function, $E_W = E_B - E_M$

For the conduction (also called free) electrons the interior of a metal may be considered as an equipotential volume.

STATEMENTS	CORRECT RESPONSE
the energy barrier at the surface of the metal. It is also measured in eV. When the electrons are within the metal E_M is (greater than/less than/equal to) E_B. At this stage photo-emission of electrons (is / is not) possible.	less than is not
33. The minimum energy that must be transferred to an electron to make it cross the potential barrier in a metal is called work-function. Refer to Fig. 2.5. Work-function of the metal is —— (complete). Work-function is a property of a particular metal ; it is usually measured in eV. Read table 1. The metals are alkali metals. Work-function of sodium is —— eV. It is (greater than/less than/equal to) that of potassium.	$E_B - E_M$ 2·46 greater than
34. Recall item 16 and re-examine Fig. 2.4. ν_0 is the threshold frequency below which no photo-emisson of electron is possible. According to the new theory about propagation of light, the quantum of energy associated with the frequency ν_0 is —— (complete). This is the minimum amount of energy which must be supplied to an electron to cross the potential energy barrier and escape. This simple argument leads us to a very important equation in photo-electricity. The work function of a metal is equal to the threshold energy that must be supplied by the incident radiation for photo-emission of electrons. In mathematical form the equation is —— (complete).	$h. \nu_0$ $E_W = h. \nu_0$
35. Read table 1. The threshold wavelength of the alkali metals lie within (ultra-violet/visible/infrared) region. Metals like zinc, etc., exhibit photoelectric effect when the incident radiation is ultra-violet. Ultra-violet radiation is short wavelength radiation and its frequency is (higher/lower) than that of visible light. $E_W = h. \nu_0$. The work-function for metals like zinc is (greater than/ less than/equal to) that for alkali metals.	visible higher greater than
36. According to Einstein the energy absorbed by an electron from an impinging radiation is used up in two ways : (i) in doing work for dragging the electron out of the atom, and then, if there is any balance, (ii) to give the electron kinetic energy to escape with some velocity.	

STATEMENTS	CORRECT RESPONSE
He computed these factors and presented the following equation known as Einstein's Photo-electric equation : $$h\nu = E_W + \tfrac{1}{2}mv_{\max}^2$$ Where, E_W = the work function of the photo-metal, $v_{\max}$ = maximum speed of the ejected electron, m = mass of the electron, h = —— and ν = ——.	Planck's constant frequency of the incident radiation
37. At the threshold frequency ν_0 the energy of the emitted electron is ——. Why ?	zero At the threshold frequency the energy of the impinging photon is just sufficient to liberate the electron without imparting any velocity to it. Hence, the KE of such photoelectron is zero
38. The work-function of sodium is 2·46 eV. The threshold energy for removal of an electron from a sodium atom is —— eV. Does sodium exhibit photo-electric effect when the incident radiation is the yellow light of wavelength 5890 ÅU ? The work-function of tungsten is 4·52 eV. Calculate the corresponding threshold frequency.	2·46 No. The energy of the incident photons is less than the work-function of sodium $1{\cdot}01 \times 10^{15}$ Hz
39. Compute the longest wavelength of radiation which will eject electron from platinum. Work-function of platinum is 6·3 eV.	$h \cdot \nu_0 = E_W$ $\therefore\ \nu_0 = \dfrac{6{\cdot}3 \times 1{\cdot}6 \times 10^{-19}}{6{\cdot}63 \times 10^{-34}}$ $= 1{\cdot}52 \times 10^{15}$ Hz $\therefore\ \nu_0 = 1972$ ÅU
40. Refer to Fig 2.4. This is a plot of kinetic energy of the photo-electrons vs. the frequency of the incident radiation. It is a straight line which (makes/does not make) an intercept with the frequency axis. The length of the intercept is ν_0 and is called the —— —— for photo-emission. It is a characteristic of the (photo-metal/incident radiation). Plotting of many such curves indi-	makes threshold frequency photometal

STATEMENTS	CORRECT RESPONSE
cate that the slope of such straight lines is always a constant. Millikan, of charge of an electron fame, measured the slopes of a number of such straight lines and found the values equal to the value of the Planck's constant, h. Recall Einstein's photo-electric equation : $h\nu = E_W + \frac{1}{2}mv_{\max}^2$. A plot of KE of photoelectrons vs. the frequency of the incident radiations following the above equation should give us a —— —— with slope ——. Millikan's experiment (verifies/fails to verify) Einstein's equation.	straight line ; h verifies
41. We come to the conclusion that the phenomenon of photo-emission of electrons can be satisfactorily explained by Einstein's equation which is based on the (quantum/wave) theory of radiation.	quantum
42. The photo-electric phenomenon suggests that light is a swarm of —— following each other with the speed of light. Photons differ from one another in their energy content depending on the —— of the light.	photons frequency

NOTE :

1. Photo-electric effect for visible and near visible light is largely a surface phenomenon because electrons of the conduction band are involved. This is why photo-electric measurements are very sensitive to the nature of the photo-surface.

2. Like photo-electric effect which (could/could not) be explained properly by the classical wave theory of light, there was another phenomenon awaiting explantion during the end of the last century. It was observed that X-rays are able to cause ionization of a gas through which they pass ; in other words, X-rays eject electrons from the atoms or molecules of the gas. But the number of ions formed is not large considering the energy of the radiation. If X-rays were waves spreading in all directions, electrons were expected to be removed from all or most of the molecules or atoms over which the rays would pass, instead from a selected few. Wave nature of electromagnetic radiation (can /cannot) explain the phenomenon of X-ray ionization.	could not cannot

3. Newton's particle theory was discarded by the physicists because it failed to explain phenomena like interference

STATEMENTS	CORRECT RESPONSE
and diffraction. Instead, the wave theory was hailed because it could explain both the phenomena with remarkable simplicity. Einstein's rejection of the wave theory raised a simple question : Did the results of photo-electric emission invalidate Young's experiments on interference ? (Yes/No). Explain.	No
	Well-known experiments on interference, conducted by Young and also other experiments on interference and diffraction, were performed only in situations involving very large number of photons. The experimental results were the averages of the many different behaviours of the individual photons. The presence of the photons is not apparent in them any more than the presence of individual droplets of water in a fine spray from a garden hose in which the number of droplets are very large. However, the experiments definitely established that photons do not travel from where they are emitted to where they are absorbed in the simple ways that classical particles like water droplets do. They travel like classical waves in the sense that calculations based on the way such waves propagate correctly explain the measurements of the average way the photons travel.
4. Einstein's explanation of the photo-electric effect considers light as an assembly of photons all moving with the speed of light. Choose the right answer : (i) Emission of photo-electrons depends on the intensity of the incident light. (ii) Work-function measures the minimum amount of energy that has to be given to an electron to make it overcome the potential energy barrier within the metallic surface. (iii) Solids, liquids and gases —— all can exhibit photo-electric effect. (iv) Intensity of incident radiation affects the energy of the emitted photo-electrons. (v) Increase in the frequency of the incident radiation increases the energy of the emitted photons. (vi) The stopping potential for a particular metal depends on the frequency of the incident radiation. (vii) Einstein's photon is unlike Newton's corpuscles.	(ii), (iii), (v), (vii)

III

Compton Effect

The most significant argument in favour of the photon nature of radiation was provided by the discovery of what the physicists of today call the 'Compton effect', after the name of the American scientist, A. H. Compton who had first observed the phenomenon around 1923. Compton reported that when X-rays fall on carbon or other materials of low atomic weight, the scattered radiation contains some rays of longer wavelength than the incident X-rays. The wavelength of the scattered radiation was observed to be independent of the material of the scatterer. That implied that the scattering did not involve entire atom. Compton suggested that the observed scattering was due to collision between the photons of energy $h\nu$ (Einstein's photon) and electrons in the target material, and went on to give a sound theoretical interpretation of the phenomenon, assuming that the electrons participating in the scattering process were free and initially at rest.

Some of the properties of the photon are discussed threadbare in course of this chapter. The reader is advised to follow the sequential development of reasonings which led to the discovery of 'Compton effect'.

STATEMENTS	CORRECT RESPONSE
1. It is a characteristic of Einstein's photon that it has no existence unless it is moving at a particular speed in a given medium. In vacuum a photon (can be at rest/must be at rest/must be moving with the speed of light). An electron (can be at rest/must be moving).	must be moving with the speed of light ; can be at rest
2. Physicists explain this particular characteristic of the photon by saying that it has no rest mass. The rest mass of a particle is its mass measured by an observer with respect to whom it is not moving. The rest mass of a particle like an electron or proton, etc., is the mass ordinarily given in tables. Is the rest mass of an electron zero ?	No. It is $9{\cdot}1 \times 10^{-31}$ kg
3. The very idea of rest mass (m_0) of a particle implies that the mass of a particle depends on its velocity	

STATEMENTS	CORRECT RESPONSE
relative to the observer measuring it. This is (like/unlike) Newtonian concept of mass. When Einstein was formulating his photon theory, he was also developing the special theory of relativity in which he could show that the mass of a particle moving with velocity v is given by the equation : $$m=\frac{m_0}{\sqrt{1-\left(\frac{v}{c}\right)^2}}$$ where, c is the velocity of light in vacuum, m_0 is the —— of the particle.	unlike rest mass
The equation shows that the mass m of a particle (depends on/is independent of) its velocity and is called the relativistic mass of the particle. The equation is called the relativistic mass equation.	depends on
4. $m=\frac{m_0}{\sqrt{1-\left(\frac{v}{c}\right)^2}}$. For most of the velocities of our daily experience v is very small compared to c. Ordinarily, therefore, the value v^2/c^2 is very small and the value $\left(1-\frac{v^2}{c^2}\right)$ is very close to (zero/one) and m is (much greater than/much less than/practically equal to) m_0.	one practically equal to
5. Subatomic particles like electrons, protons, etc., can acquire velocities very close to the speed of light in modern particle accelerators. In such cases v^2/c^2 is very close to (one/zero), the expression $\left(1-\frac{v^2}{c^2}\right)$ is very close to (zero/one) and m is (much greater than/much less than/practically equal to) m_0.	one zero much greater than
6. Recall relativistic mass equation. When we are dealing with a photon whose rest mass is —— (complete) and whose speed of propagation in any medium is equal to that of —— (complete), the above equation becomes (0/0) which is a meaningless expression.	zero light
7. Substituting $m_0=0$, and $v=c$ for a photon in the relativistic mass equation, we get $m=0/0$ which has no mathematical meaning. For this reason we are not allowed to use m for a photon in equations we would ordinarily use for particles. A particle of mass m	

STATEMENTS	CORRECT RESPONSE
moving with velocity v has kinetic energy because of its motion. We compute this energy by the equation $E=\frac{1}{2}mv^2$. Is it possible to determine the KE of a photon with the help of this equation? (Yes/No). Explain.	No.
	Mass as conceived in case of the particle has no meaning in case of the photon. Hence the equation $KE=\frac{1}{2}mv^2$ cannot be used for calculating the KE of the photon
8. As photons cannot exist unless they are moving with the speed of light, their entire energy is kinetic. The energy of a photon is the product $h\nu$; the KE of a photon is the product —— (complete).	$h\nu$
9. The total energy and KE of the photon (are/are not) the same. One of the most important properties of a particle is its KE We (are/are not) able to associate a definite KE with a photon.	are are
10. $E=h\nu$; photons always travel with the speed of light. If the energy of a photon is reduced due to an interaction with matter, we can expect (its speed / the frequency of the radiation associated with it) to be reduced.	the frequency of the radiation associated with it
11. The KE of the photon associated with yellow light ($\nu=5{\cdot}1\times10^{14}$ Hz) is —— joule (compute). It is a general convention to measure the energy of a photon in electron volt. One eV is equal to $1{\cdot}602\times10^{-19}$ J. The energy of the photon described above is —— eV.	$3{\cdot}38\times10^{-19}$ J $2{\cdot}11$ eV
12. A particle in motion carries momentum. This is another important characteristic of a particle. From mechanics we know that the momentum P of a particle of mass m and velocity v is given by $P=$ —— (complete); here, m is the (rest/relativistic) mass when $v>0$.	mv relativistic
13. We can conclude from the above discussion that the photon behaves like a particle in motion. It (carries/does not carry) momentum.	carries
14. Momentum equation $P=m\vec{v}$ cannot be used for measuring the momentum of a photon because there is no determinate value for the (velocity/relativistic mass) of a photon. We return to the classical electromagnetic concept and associate a wave with a photon.	relativistic mass

STATEMENTS	CORRECT RESPONSE
If the wave corresponds to frequency ν, the momentum of the photon is given by $P=\frac{h\nu}{c}$. Can you deduce the equation ? The momentum of the photon associated with the green light of frequency 6×10^{14} Hz is —— kg m/sec.	$1{\cdot}33\times10^{-27}$
15. For every photon associated with radiation of wavelength λ and frequency ν, the momentum P ——, in terms of λ.	$=h/\lambda$
16. The momentum of the photon associated with radiation of wavelength 10^{-10} m is —— kg m/s.	$6{\cdot}63\times10^{-24}$
17. Einstein's photon is more complex and complicated than Newton's corpuscle. It does not exist when (at rest/in motion). Considered as a particle in ——, a photon has both —— and ——. It differs from ordinary particles such as electrons, protons, etc., in that its rest mass is zero.	at rest ; motion KE, momentum
18. Reader should carefully note here that the relativistic mass equation when applied to photon gives us (zero/indeterminate) value of its mass. For this reason we use the (particle/wave) characteristic of the photon while computing its KE and momentum.	indeterminate wave
19. This apparent contradiction in describing the photon was explained by conceiving wave-particle duality of matter. Physicists had to accept the idea that in certain situations, for example when it exhibits interference and diffraction, light radiation behaves as if it were composed of (waves/particles), and in other situations like photoelectric effect, etc., light radiation behaves as if it were composed of (waves/particles).	waves particles
20. Our study of photoelectric emission leads us to the conclusion that the concentration of photon energies into quanta enables them to behave like particles in their interaction with electrons and other classical particles. The photon has —— —— zero. Its KE and momentum are computed by associating with it certain physical quantities which are characteristics of (waves/particles).	rest mass waves
21. Physicists studying photoelectric phenomenon have never reported anything except photoelectrons coming out from the photo-metal after incident light has inter-	

STATEMENTS	CORRECT RESPONSE
acted with it. Einstein's equation forbids survival of a photon after an interaction with an electron. There is no evidence as such to indicate that in photoelectricity photon survives an interaction. (All/some/none) of the KE of a photon involved in ejecting a photoelectron is transferred to the electron in an interaction.	All
22. Our experience with particles in general is that the phenomenon as described in item 21 is not always true for particles interaction. When one mass collides with another, it (is/is not) usually the case in which one mass stops completely and transfers its entire KE to the other.	is not
23. Photons are particles in motion. We can, therefore, expect them to survive an interaction with matter. The surviving photons will have, after the interaction, some what changed KE and momenta. This (occurs /does not occur) in photoelectric effect.	does not occur
24. In 1923 A. H. Compton analysed the results of bombarding a suitable target with X-rays as described in the preface to the present chapter. Figures (3.1) and (3.2) represent a much simplified picture of Compton scattering. Scattering refers to the phenomenon in which a X-ray photon transfers some of its energy to the electron it interacts with and in the process suffers deviation from its original path having (the same/a higher/a lower) frequency. Photons which produce photoelectrons (undergo/do not undergo) Compton scattering.	a lower; do not undergo
25. Refer to Fig. 3.1. Before collision with the electron, the impinging X-ray photon has frequency ν_1. Its KE before the collision is —— and its momentum ——. If the electron, which is at rest, and the photon constitute an isolated system, the total momentum of the system before the interaction is —— (in terms of ν_1).	$h\nu_1$; $h\nu_1/c$; $h\nu_1/c+0=h\nu_1/c$

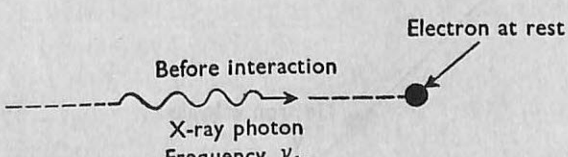


Fig. 3.1

STATEMENTS	CORRECT RESPONSE
26. Refer to Fig. 3.2. After the collision the X-ray photon has freqency ν_2 and the electron is (at rest/moving). (all/some/none) of the KE of the X-ray photon has been transferred to the electron during the collision.	moving some
27. Fig. 3.2 describes the phenomenon known as Compton ——. Frequency ν_2 is (higher than/lower than/equal to) ν_1. After collision the interacting photon moves in a direction which is (same as/different from) its initial direction of propagation. Its KE is (less than/equal to/greater than) that before the collision.	scattering, lower than different from less than
28. If m be the mass of the electron and v its velocity after collision with the photon, its momentum after the collision is mv. The momentum of the photon after the collision is —— .	$h\nu_2/c$
29. When two or more particles constitute an isolated system and interract with each other, the total (momentum / KE) of the system must be conserved. It is found in this experiment (Fig. 3.2) that $h\nu_1/c = h\nu_2/c + m\vec{v}$. Compton scattering provides yet another evidence for the (photon/wave) theory of electromagnetic radiation. Explain.	momentum photon
30. Recall Item 19. When electromagnetic radiation exhibits such effects as interference and diffraction, we apply the (photon/wave) theory to explain them.	wave

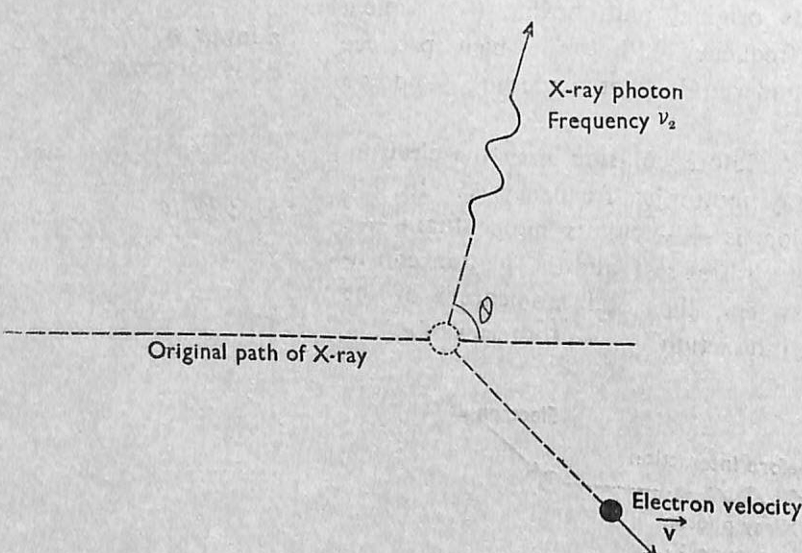


Fig. 3.2

STATEMENTS	CORRECT RESPONSE
When it exhibits photoelectric effect and Compton scattering, we apply the (photon/wave) theory to explain their occurrences. This selective use of theories to account for different effects of electromagnetic radiation is called the —— duality.	photon wave-particle
31. Refer to note 2 of Chapter II. Ionization by X-rays requires direct encounter between X-ray photons and electrons present in atoms and molecules. Since such encounters are not too common, it is possible to understand why the extent of ionization produced by X-rays is less than that which would be expected from wave motion spreading in all directions.	
Photons of the incident X-ray radiation collide randomly with the gas molecules when they pass through a gaseous medium. On the average a (small/large) number of direct interactions between photons and electrons in atoms take place. (wave/photon) theory of radiation can successfully explain the ionization of gaseous medium by X-rays.	small photon
32. Which of the following are true ? (1) In Compton scattering all the KE of the X-ray photon is transferred to the electron with which it interacts. (2) In Compton scattering the total momentum of the X-ray photon and electron system is conserved. (3) The relativistic mass of any particle moving with a speed greater than zero is greater than its rest mass. (4) As the wavelength of a photon increases its momentum increases. (5) The higher the frequency of a photon the greater is its momentum. (6) The photon is another name for the Newtonian particle of light. (7) A photon is a quantum of energy carried by electromagnetic radiation. (8) In Compton scattering the scattered photon has a lower frequency than that of the incident photon.	(2), (3), (5), (7), (8)

STATEMENTS	CORRECT RESPONSE
NOTE	
(1) To compute the physical property of the photon (energy or momentum) we use the —— or —— of the electromagnetic radiation associated with it.	frequency ; wavelength
(2) Calculate the KE of a photon associated with X-rays of wavelength 2×10^{-10} m.	6·21 keV
(3) Calculate the momentum of a photon associated with the ultra-violet radiation of wavelength 3×10^{-7} m.	$2{\cdot}21 \times 10^{-27}$ kg m/s
(4) Do you observe Compton effect with visible light ? (Yes/No). Explain.	

The change of wavelength of the incident photon due to Compton scattering by the electron of a scatterer is known as Compton shift, usually represented by the symbol $\triangle\lambda$. The value of this shift is independent of the mass of the scatterer, hence, by/replacing the electron mass by the atomic mass of the scatterer for computing the value of $\triangle\lambda$, no change is observed. When the incident radiation is the visible light, wavelength λ is very large compared to the Compton shift $\triangle\lambda$. As a result the scattered radiation in this region of the electromagnetic spectrum will, in all circumstances, have a wavelength which is same as the wavelength of the incident radiation within experimental accuracy.

(5) The process which scatters photon without changing their wavelength is called Thomson scattering or forward scattering. This phenomenon can be explained from the point of view of the wave theory of light. (classical/quantum) concept of electromagnetic radiation is enough to explain forward scattering.	classical
(6) Read item 4 above. We conclude that it is in the short wavelength region that the classical theory fails to explain the scattering of radiation. Wave theory (can / cannot) explain Compton scattering. Such failures to explain certain phenomena in short wavelength region, i.e., in the ultra-violet region is commonly known as 'Ultra-violet Catastrophe' of classical physics. This limitation of the classical physics paved the way for the development of quantum physics.	cannot

STATEMENTS	CORRECT RESPONSE
(7) Let's have a look at the size of the Planck's constant h. At long wavelength the frequency ν is small and hence $h\nu$ is also small. As such the granularity in electromagnetic energy, $h\nu$, is so small as to be virtually indistinguishable from the continuum of classical physics. At sufficiently short wavelength when ν is large enough, $h\nu$ is no longer too small to be negligible and quantum effects abound.	
(8) Compute the frequency, wavelength and momentum of a photon whose energy equals the rest mass energy of an electron. Rest mass of an electron is —— (complete).	$9{\cdot}1\times10^{-31}$ kg $1{\cdot}24\times10^{20}$ Hz $2{\cdot}42\times10^{-12}$ m $2{\cdot}74\times10^{-22}$ kg m/s
(9) In Compton scattering the frequency of the scattered radiation (depends/does not depend) on the material of the scatterer. This implies that the scattering does not involve the (entire atom/orbital electron).	does not depend entire atom
(10) Which of the following statements are true ? (i) The relativistic mass of a photon is zero. (ii) The rest mass of an electron is zero. (iii) X-ray photons have greater kinetic energy than visible light photons. (iv) In Compton scattering the scattered photons have shorter wavelengths associated with them than the incident photons. (v) In Compton scattering the scattered photons are of slower speed compared to the incident ones. (vi) In Compton scattering the scattered photons are of lower frequency than the incident photons. (vii) Quantum theory of radiation can adequately explain Compton effect. (viii) Wave theory of radiation can adequately explain Compton effect.	(iii) ; (vi) ; (vii)
(11) Black-body radiation, photoelectric emission and Compton scattering are physical phenomena which (can / cannot) be explained by classical concept in physics. Quantisation of energy is the foundation of	cannot

STATEMENTS	CORRECT RESPONSE
Quantum physics which (can / cannot) adequately explain the above phenomena. Quantum concept, however, does not discard the classical one as wrong or invalid. The apparent contradiction is resolved by considering classical physics as a special limiting case of quantum physics.	can

(12) Discuss the following problem to understand the difference between continuous and discontinuous energy exchange :

A pendulum consisting of a bob of mass 0·01 kg, suspended by a string of 0·1 m length, oscillates with a maximum amplitude of 0·1 rad. The energy of the pendulum decreases due to frictional effects. The frequency of oscillation of the pendulum is :

$$\nu=\frac{1}{2\pi}\sqrt{g/l}=\frac{1}{2\pi}\sqrt{\frac{9\cdot8}{0\cdot1}}=1\cdot6\text{ Hz.}$$

The energy of the pendulum is the maximum potential energy of its bob$=$m.g.h.$=$m.g.l $(1-\cos\,\theta)=4\cdot9\times10^{-5}$ J. Assuming that the energy of the pendulum is quantised so that the change in energy takes place in discontinuous jumps of magnitude $\triangle E=h\nu=6\cdot63\times10^{-34}\times1\cdot6=10^{-33}$ J.

$$\therefore\ \frac{\triangle E}{E}=\frac{10^{-33}}{4\cdot9\times10^{-5}}=2\times10^{-29}$$

Hence to be able to observe the discreteness in the energy decrease we need to measure the energy better than 2 parts in 10^{29}. It is obvious that even the most sensitive experimental setup is also totally incapable of this energy resolution. We, therefore, conclude that experiments involving an ordinary pendulum cannot determine whether Planck's postulate about energy quantisation is valid or not. The same is true of all other macroscopic mechanical systems. The smallness of h makes the graininess in energy too fine to be distinguished from an energy continuum. Indeed, h might as well be zero for a classical system. One way to reduce quantum formulae to corresponding classical ones would be to make $h\to0$ in them. Only in systems where we consider ν large and/or energy E small, so that $\triangle E=h\nu$ is of

STATEMENTS	CORRECT RESPONSE
comparable order to E, are we in position to test Planck's postulate. One example, of course, is the high energy standing wave in black-body radiation.	
(13) For quantum effects to be everyday phenomena in our life, what should be the minimum order of the magnitude of h ?	

For an answer the reader is advised to discuss the matter with his physics teacher.

Taking one thousandth of a joule as the minimum limit of perceivable energy in our daily life, h should be of the order of 10^{-18} Js.

IV

Matter Wave

The situation reached now appears to be contradictory : having first known that radiations consist of electromagnetic waves, it has been established fairly convincingly that radiations are emitted, transported through space and absorbed as energy particles. Careful analysis of the state of affair shows, however, that there is a possible way out of this apparent paradox. The interference and diffraction are possible only if radiation has a wave structure whereas the photoelectric phenomenon and Compton effect imply that radiation consists of particles rather than waves. In other words, radiation may be regarded as exhibiting a dual wave-paaticle behaviour ; some of the properties of radiation may be wave like, while some others are particle like.

This dualism of the wave and particle functions of radiation led de Broglie of France to suggest in 1923 that a similar dualism might exist for material particles and electrons. His proposal was that the wave-particle dualism represented something that was perhaps fundamental to the nature of the universe. By means of Planck's quantum theory expression and Einstein's mass-energy relationship, de Broglie showed that a particle of mass m moving with velocity v would be associated with waves of length given by :

$$\lambda=\frac{h}{m.v}$$

Similarly, radiation of wavelength λ will be equivalent to a particle of mass $\frac{h}{\lambda \cdot v}$, moving with the speed v. (For radiation, v=velocity of light).

STATEMENTS	CORRECT RESPONSE
1. In the last chapter we derived that the rest mass of the photon is (zero/indeterminate) : its relativistic mass computed by substitutions in equation $m=\frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$ is (zero/indeterminate).	zero indeterminate
2. We recapitulate. The relativistic mass equation, $m=\frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$ fails to help us determine mathematically	

STATEMENTS	CORRECT RESPONSE
the relativistic mass of the photon. This does not mean that we cannot compute the mass equivalent of the energy of a photon. In his special theory of relativity, Einstein established the relationship between energy and its equivalent mass given by $E=mc^2$, where c is the velocity of —— in vacuum, i.e., 3×10^8 m/s. This equation enables us to compute the mass equivalent of any energy or energy equivalent of any mass.	light
Compute the energy equivalent of the rest mass of an electron : $m_0=9{\cdot}1\times10^{-31}$ kg.	$8{\cdot}2\times10^{-14}$ J
3. Compute the mass equivalent of an energy of 9×10^6 J.	10^{-10} kg
4. Let m_{ph} be the mass equivalent of a photon. Its energy $E=m_{ph}{\cdot}c^2$. The energy of the same photon in terms of its frequency ν is $E=$ —— .	$h{\cdot}\nu$
5. For any photon with mass equivalent m_{ph} and frequency ν, (i) $E=m_{ph}{\cdot}c^2$ (ii) $E=h{\cdot}\nu$ (iii) $m_{ph}=$ —— (in terms of).	$h{\cdot}\nu/c^2$
6. (i) $m_{ph}=h{\cdot}\nu/c^2$ (ii) $\nu=c/\lambda$ (iii) Substituting c/λ for ν in (i), $m_{ph}=$ —— where m_{ph} represents the —— —— of a photon.	$h/c{\cdot}\lambda$ mass equivalent
7. The mass equivalent of a photon can be estimated if we use the expression —— or —— .	$h{\cdot}\nu/c^2$; $h/c\lambda$
8. The rest mass of a photon, which has frequency $7{\cdot}5\times10^{14}$ Hz (or c.p.s.) in the violet end of the visible spectrum, is —— kg. The mass equivalent of this photon is —— .	zero $5{\cdot}5\times10^{-36}$ kg
9. The wave-particle duality, which we had had to associate with light and all other electromagnetic radiation, was not accepted by scientists without any misgivings. Some argued that the radiation ought to consist of either waves or particles but not both. However, despite their philosophical uncertainty and confusion, they were faced with the facts of interference and diffraction on one hand and the photoelectric effect, Compton scattering and ionization by X-rays on the other hand ; adequate explanation of these phenomena involved the wave-particle —— of radiation.	duality

STATEMENTS	CORRECT RESPONSE
10. In 1923 Louis de Broglie enunciated a novel hypothesis. He contended that it was unreasonable to single out only photon, of all kinds of particles in nature, as being associated with waves. He suggested that all particles (electrons, protons, atoms, cricket ball, air-bus, satellites, even professor of physics) have wave characteristics associated with them. According to de Broglie, in addition to its mass, momentum and energy, we ought to be able to measure —— and —— of the wave associated with any material particle.	wavelength ; frequency
11. de Broglie's proposal was essentially that the —— dualism represents something that is perhaps fundamental to the nature of the universe.	wave-particle
12. The hypothesis that all particles are associated with waves was first stated by (Einstein/de Broglie). The hypothesis that radiation behaved, in certain interactions, as if it consisted of particles was first stated by (Einstein/de Broglie).	de Broglie; Einstein
13. We know that Huygen enunciated his hypothesis that light consisted of waves at a time when Newton was formulating his corpuscular (particle) theory of light. One reason why the wave hypothesis was not accepted then was that Huygen was not able to suggest any practical step to measure the frequency or wavelength of the light waves. Once Young could measure the wavelength of light from his experiments on interference, he was able to explain why the phenomena like interference and diffraction were not observed in daily life. The wave theory was accepted immediately thereafter. de Broglie's hypothesis would have been a figment of imagination if he had failed to suggest some method for computing the wavelength and frequency of the matter waves associated with a particle. Re-read item 6. If m be the mass equivalent of a photon, then $m=\frac{h}{c\lambda}$. Therefore, $\lambda=\frac{h}{m\cdot c}$; here c represents the velocity of the photon and the product $m\cdot c$ represents its ——.	momentum

STATEMENTS | **CORRECT RESPONSE**

14. $m_{ph} = \frac{h}{\lambda c}$; this is an equation for the —— —— of the energy of a photon. If p is the momentum of the photon, then $\lambda =$ —— .

mass equivalent

$\frac{h}{p}$

15. de Broglie suggested that the equation $\lambda = \frac{h}{p}$ should be used to determine the wavelength of the matter wave associated with any particle whatsoever. If m be the relativistic mass of an electron moving with velocity v, then $p =$ —— and $\lambda =$ —— .

mv; $\frac{h}{mv}$

16. A particle with a relativistic mass of $1{\cdot}0 \times 10^{-30}$ kg is moving with a speed of 9×10^{6} m/sec. Compute the wavelength of the matter wave associate with it.

$7{\cdot}37 \times 10^{-11}\text{m} = 0{\cdot}737$ Å

17. Matter wave associated with a moving mass is also known as de Broglie wave. Compute the de Broglie wavelength of a cricket ball moving at the speed of 40 m/sec. Mass of the ball = 160 gm.

$$\lambda = \frac{h}{mv} = \frac{6{\cdot}63 \times 10^{-34}}{0{\cdot}16 \times 40}$$
$$= 1{\cdot}03 \times 10^{-34}\text{m}$$
$$= 1{\cdot}03 \times 10^{-26} \text{ Å}$$

18. An airliner has a mass of about 10^{6} kg and is flying at a speed of 1000 km/hr. Compute the wavelength of the de Broglie wave associated with it.

$$\lambda = \frac{6{\cdot}63 \times 10^{-34}}{10^{6} \times \frac{1000 \times 1000}{3600}} = 2{\cdot}39 \times 10^{-42}\text{ m} = 2{\cdot}39 \times 10^{-32} \text{ Å}$$

19. An electron has KE of 100 eV. Compute its de Broglie wavelength, $m = 9{\cdot}1 \times 10^{-31}$ kg.
Compute the de Broglie wavelength of a neutron of energy 1 eV. Mass of neutron $= 1{\cdot}676 \times 10^{-27}$ kg.

$E = \frac{1}{2} mv^2$ or $mv^2 = 2E$ or $mv = \sqrt{2mE}$.

$$\therefore \quad \lambda = \frac{h}{\sqrt{2mE}}$$

$$\therefore \quad \lambda_e = \frac{6{\cdot}63 \times 10^{-34}}{\sqrt{2 \times 9{\cdot}1 \times 10^{-31} \times 100 \times 1{\cdot}6 \times 10^{-19}}}$$
$$= 1{\cdot}2 \times 10^{-10}\text{ m} = 1{\cdot}2 \text{ Å}. \quad \lambda_n = 0{\cdot}286 \text{ Å}$$

20. $\lambda = \frac{h}{mv}$; where v is the velocity of the moving particle ($v < c$), is the equation for the wavelength of (a matter wave/electromagnetic wave associated with a photon).

a matter wave

21. Re-read the Items 16–19. Calculations show that unless the mass m is very small, such as in the case of electron and other sub-atomic particles and the lightest known atoms, like hydrogen, helium, etc., the wavelength of the

STATEMENTS	CORRECT RESPONSE
matter waves are so short that there are no means at present at our disposal for their detection. Matter waves associated with high speed objects like jet airliners, or artificial satellites moving with escape velocity (can/cannot) be experimentally determined.	cannot
22. From our studies on optics we know that the occurrence of —— and —— are very good evidence of the existence of waves.	interference ; diffraction
23. In Items 16 to 19 we have computed the wavelengths of the matter waves associated with particles whose masses are comparable to that of electron, neutron, cricket ball, etc. The wavelength of the matter waves associated with an electron like particle is of the order of —— ; the wavelength of the matter wave associated with the fast moving cricket ball is about —— ÅU. We are (more/less) likely to observe interference and differaction of electron matter waves than cricket ball matter waves.	10^{-10} m, i.e., 1Å 10^{-24} more
24. Observable optical phenomena like interference and diffraction are more likely for (subatomic particles /cricket balls).	subatomic particles
25. The wavelength of the matter wave associated with an electron of moderate energy is of the order of —— m. The spacing of atoms and molecules in crystals (are/are not) of the same order.	10^{-10} m are
26. Recall Item 25. Crystals (should / should not) be capable of producing diffraction effects with electron matter waves. Elsasser of Germany put forward this suggestion in 1925.	should
27. The first definite proof that electrons can be diffracted and that they exhibit —— as well as the familiar —— properties was obtained in the Bell Telephone Laboratories in New York by Davisson and Germer in 1927. A beam of electrons was accelerated and given a specific velocity by passage through a known potential difference. The electrons in the beam were then reflected and scattered by a nickel crystal. The study showed that the electrons behave like waves rather than like particles. The experimental result obtained by them by using electrons which had been accelerated by passage through a potential of 54 volts, was in	wave ; particle

STATEMENTS	CORRECT RESPONSE
agreement which the result expected from the radiation of wavelength 1·65 ÅU. The computed value of the wavelength of de Broglie waves associated with such electrons is given by the eqn. $\lambda = \frac{h}{\sqrt{2mE}}$, is —— Å	1·67
Thus the experimental result agreed (very well/badly) with the theoretical prediction.	very well
28. Another experiment to demonstrate the existence of matter-waves of moving electrons is described in Figs. 4.1 (a), 4.1 (b) and 4.1 (c). The experiment was devised by Mollenstedt to demonstrate matter-wave interference. In Fig. (a) a beam of electrons is fired from an electron gun, *G*, which falls on a photographic plate. Incident electrons darken the plate. In Fig. (b) a thin metal wire is placed on the path of the beam. There is a 'shadow' of the wire on the film. The figures (a) and (b) (exhibit/do not exhibit) matter-wave interference.	do not exhibit
29. In Fig. (c) the metal wire is given some positive charges. The charge on the wire bend the path of the electrons on either side of it such that they intersect. As the electrons from the same source intersect, interference of matter-wave (may/may not) occur. The resulting pattern on the film is [(1) several light and dark fringes/ (2) shadow of the wire].	may (1)
30. Fig. (c). In the pattern of light and dark fringes formed in the film, the dark fringes are the places where the film has been exposed to the electrons. These are produced by (constructive/destructive) interference of matter-waves associated with the electrons. The light fringes are non-exposed parts of the film and are due to (constructive/destructive) interference of the matter-waves.	constructive destructive
31. Results of the Mollenstedt experiment, described in items 28 through 30, can only be explained if we associate —— with the electrons of the beam.	matter-waves
32. Davisson and Germer experiment showed that electron beams undergo (diffraction/interference); Mollenstedt experiment showed that electron beams undergo (diffraction/interference). Both the experiments conclusively prove that electrons (have/do not have) wave character.	diffraction interference have

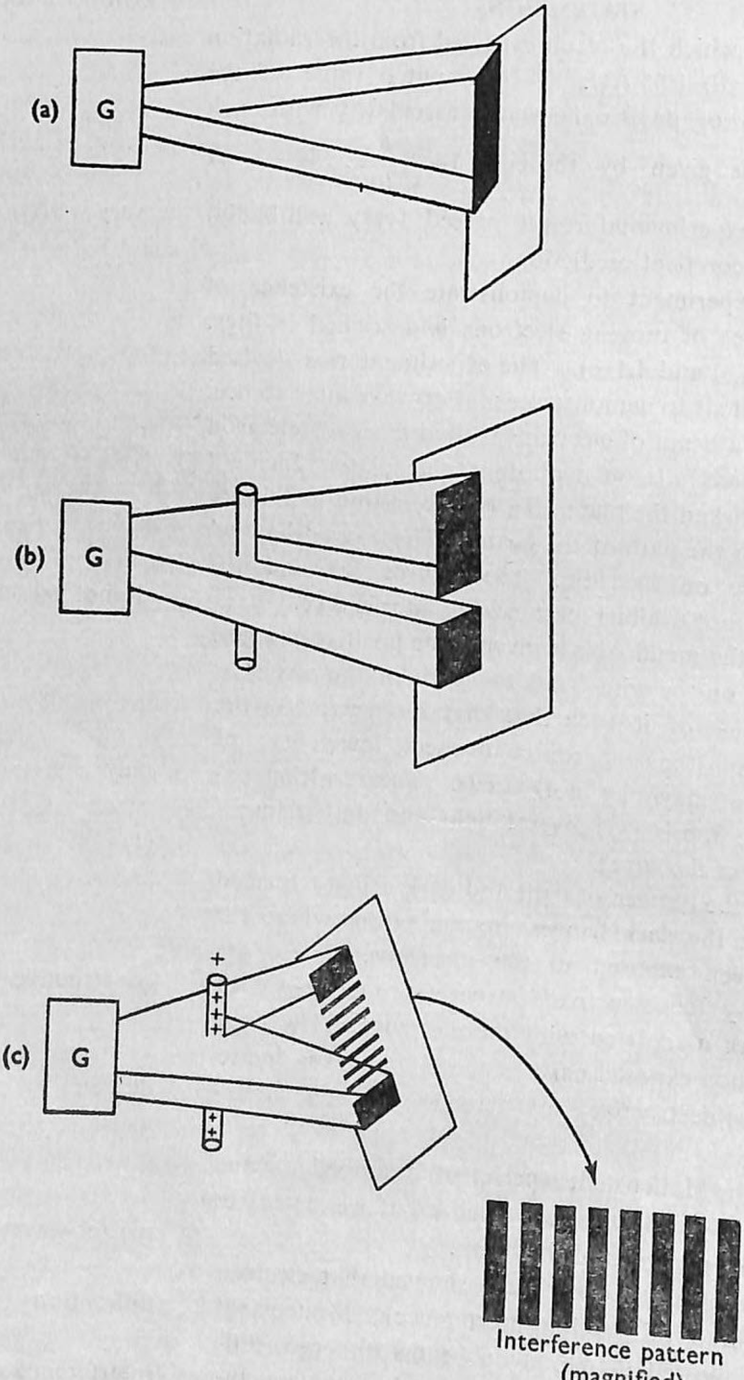
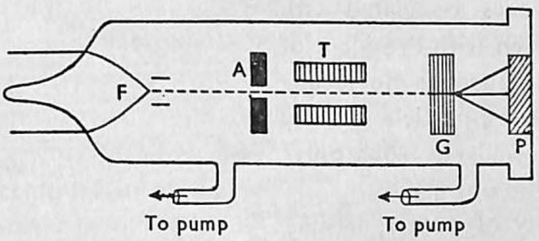


Fig. 4.1

STATEMENTS	CORRECT RESPONSE
33. G. P. Thomson in 1927 devised another experiment to demonstrate the existence of electron matter-wave. He passed a stream of fast electrons through a thin gold foil and then allowed the resulting beam to fall on a photographic plate, Fig. 4.2 (a). Upon development the plate showed a diffraction pattern consisting of a series of concentric circles, Fig. 4.2(b), indicating that the electrons were manifesting —— properties.	wave
It is of special interest to mention that the diffraction pattern could be distorted by means of a magnet. This showed that the pattern was actually produced by (electrons/ other extraneous radiations such as X-rays which might be present).	electrons



$A \rightarrow$ anode
$T \rightarrow$ metal block for capillary passage
$G \rightarrow$ thin (μ m)gold foil
$P \rightarrow$ photographic plate $\rightarrow$ diffraction rings

Fig. 4.2 (a)

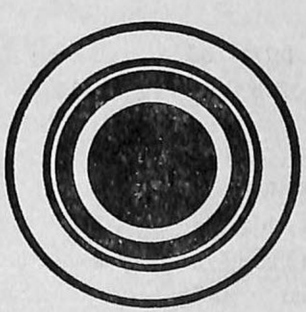


Fig. 4.2 (b)

Diffraction ring as observed in Thomson experiment

STATEMENTS	CORRECT RESPONSE
34. Electron microscope is an instrument used for the examination of particles much too small to be visible in the best optical instruments. The microscope depends on the behaviour of electrons as waves. Since 1927, the study of the wave properties of electrons has become commonplace in advanced scientific laboratories. In the last fifty years or so many experiments have shown that beams of atomic and subatomic particles, charged or uncharged, like electrons, protons, neutrons, hydrogen atoms, helium atoms, etc. undergo diffraction and both constructive and destructive interference under suitable experimental conditions. There is no evidence to suggest that de Broglie's hypothesis would not be verified if we could find conditions suitable for observing the matter-waves associated with cricket balls, airlines, bullets and even with President of India. At the moment, however, there is no means to accomplish the study. The wave-particle duality applies to (photons only/photons and electrons only/subatomic particles only/any material object).	any material object
35. In view of the wave-particle duality of matter, it may be wondered if there is any point in making a distinction between a wave and a particle. In a sense, such a distinction is meaningless, since everything exhibits wave behaviour or particle behaviour depending on the circumstances. We explain the interference fringes in terms of (waves/particles), the photo-electric effect in terms of (waves/particles). This prompted Neils Boer to propose a law called the Principle of Complementarity in the following words :	waves particles
'We can describe physical phenomena in terms of particles or in terms of waves ; where one approach fails the other succeeds'.	
Compton scattering cannot be explained in terms of wave theory of X–rays; it (can/cannot) be explained in terms of the particle (photon) theory. Is this an example of the principle of Complemetarity ? (Yes/No).	can yes
36. Results of the experiments performed by Davisson and Germer, Mollenstedt and Thomson cannot be explained in terms of the particle nature of the electrons. These can be satisfactorily explained only in terms of matter	

STATEMENTS	CORRECT RESPONSE
waves associated with them. These are examples of Bohr's Principle of —— .	Complementarity
37. The wave-particle duality and the Principle of Complementarity involve two possible sets of physical quantities, energy, E and momentum, p on one hand and wavelength and frequency, on the other, to explain some physical phenomena. There (are/are not) equation(s) which relate one of these sets (E and p) with the other (λ and ν) ; the physical quantities used to desribe particles (are/are not) independent of those used to discuss the associated waves.	are; are not
38. Given a particle of relativistic mass m, moving with velocity v and momentum p. The wavelength of the matter wave associated with it is given by : —— (in terms of p) or —— (in terms of m and v).	$\frac{h}{p}$; h/mv
Given a photon associated with an electromagnetic wave of frequency ν and wavelength λ. The KE of the photon is ——. The momentum of the photon is ——.	$h\nu$; $\frac{h\nu}{c}$
39. The reader should note the following subtle difference between a photon and a particle. A photon has no (rest mass/relativistic mass) while a particle has the both. Momentum of a photon changes without any change in its velocity because photon (always/sometimes/never) moves with the velocity of light. The momentum of a particle changes when its velocity changes.	rest mass; always

Note :

1. Which of the following statements are true ?
   - (i) Ordinary man made gratings have narrow enough slits to produce observable diffraction effects with matter waves.
   - (ii) Only charged particles have matter waves assoiated with them.
   - (iii) When the speed of a particle increases, the wavelength of the matter wave associated with it also increases.
   - (iv) All material particles have matter waves associated with them.
   - (v) The Principle of Complemetarity states that no material particle can move with the speed of light in vacuum.

   Correct response: (iv)

STATEMENTS	CORRECT RESPONSE
2. Is electron a particle ? Is it a wave ? Explain. *Explanation* : Scientists agree that it is a particle. But then its particle aspects are emphasised when its emission and absorption are studied and the wave aspects are emphasised when its behaviour while moving through a system is studied. The wave aspects of its motion become more difficult to observe when its wavelength becomes shorter.	
3. Recall Item 20. The nature of the so-called matter waves of de Broglie still presents a problem. It is known that they (are/are not) electromagnetic wave like X-rays or γ-rays. Although the wavelengths of matter wave may, under certain circumstances, be similar to X-rays or γ-rays, what they are is not evident. Quantum mechanics provides us with an interpretation to get away with this ambiguity. According to it any actual wave propagation for matter wave is ruled out. Instead, it is considered that a stream of moving particles behave like a train of waves merely because the statistical probability of finding a particle at any points in its path is represented by a wave equation. Why such an equation rather than some other form, should give the distribution of the particles in space remains unexplained. It is possible that this view may have to undergo modification in the future, but for the present it is accepted at least as a working hypothesis.	are not
4. *An episode* : J. J. Thomson was the first to discover existence of electron in 1897. He characterised the electron as a particle with a definite charge to mass ratio. He was awarded Noble Prize in 1906. Thirty years later his son G. P. Thomson exprimentally demonstrated the occurrence of electron diffraction in 1927 and was awarded the Noble Prize (with Davisson) in 1937. Max Jimmer writes of this : 'One may feel inclined to say that Thomson, the father, was awarded the Noble Prize for having shown that the electron is a particle and Thomson, the son, for having shown that the electron is a wave'.	

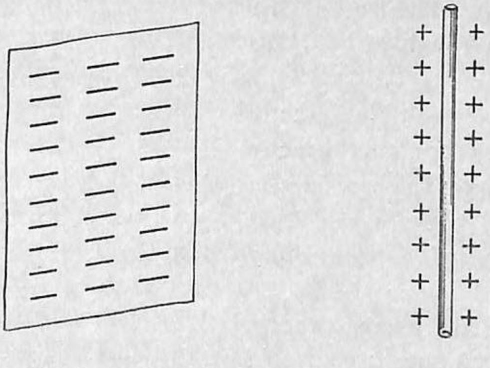
V

Rutherford's Atomic Model :

It is well-known even to a school student of physics that the structure of an atom is like that of our familiar solar system. The idea was first put forward by Lord Rutherford during the second decade of the present century. Accordingly an atom is pictured as consisting of a central positively charged nucleus which is responsible for practically the entire mass of the atom and a number of electrons describing close circular orbits round the nucleus ; for atoms of different elements there are different number of electrons in the orbit(s). The positive charge in the nucleus is exactly balanced by the negative charge carried by the electrons and this accounts for electrical neutrality of an atom.

The present chapter is devoted to the sequential development of the ideas which led Rutherford to propose his theory.

STATEMENTS	CORRECT RESPONSE
1. It is common knowledge that vigorous rubbing of a glass rod with a silk cloth gives the rod, what is called positive charge and the cloth negative charge, Fig. 5.1. Before it is charged, the glass rod contains equal numbers of positively and negatively charged particles. When rubbed with silk, the particles that leave the glass rod are (positively/negatively) charged and are	negatively



Silk cloth Glass rod

Fig. 5.1

STATEMENTS	CORRECT RESPONSE
called ——. Thus, the glass rod (gains/loses) electrons and the silk cloth (gains/loses) electrons.	electrons ; loses gains
2. The glass rod and the silk cloth of Fig. 5·1 are composed entirely of small electrically netural particles called atoms. This is true of any other material object. Recall your study of photo-electric emission in Chapter II. In photo-electric as well as thermoionic emissions the particles that leave the metal are ——. The —— removed from the glass and also emitted by the metal in photo-electric or thermionic effect come from the constituent atoms. To account for the electrical neutrality of the atom we must assume that it contains parts which are electrically (positive/negative).	electrons electrons positive
3. Every atom is electrically neutral and consists, at least in part, of (equal/unequal) amounts of positive and negative charges.	equal
4. The mass of the electron as estimated from many experiments is $9{\cdot}1 \times 10^{-31}$ kg. The mass of the smallest and lightest atom (of hydrogen) is $1{\cdot}67 \times 10^{-27}$ kg. The ratio of the mass of a hydrogen atom to that of an electron is —— .	about 1835.
5. Any atom has a mass which is (much less than/equal to/much greater than) the mass of an electron. An atom is electrically (neutral/positive/negative) because it contains (equal/unequal) numbers of positive and negative carriers of charge.	much greater than neutral equal
6. The mass of a hydrogen atom is known to consist entirely of the mass of its positive charge carrier(s) and that of its negative charge carrier (s). The mass of the positive charge carrier in an atom is roughly (0·001/100 /2000) times that of an electron.	2000
7. It is known that an atom of carbon contains exactly 6 electrons. An atom of oxygen contains exactly 8 electrons. The total positive charge which resides in a carbon atom is —— elementary charges and that which resides in an oxygen atom is —— elementary charges.	6 8
8. Chemical experiments indicate that the average radius of an atom is 10^{-10} m. Can you compute it yourself? Recall that 1 Å $= 10^{-10}$ m. The radius of an atom is about —— Å.	1

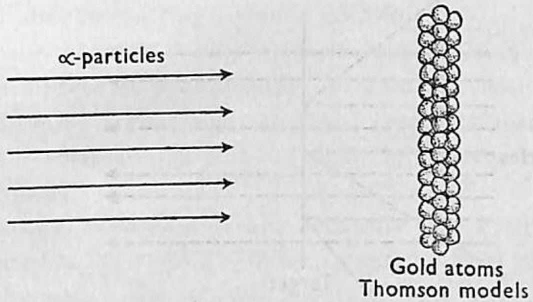
STATEMENTS	CORRECT RESPONSE
Soln. : An approximate estimate of molecular and atomic *radius* can be made by utilising Loschmidt's assumption that a liquid or, better, a solid may be treated as an arrangement of closely packed spherical molecules (or atoms). The molecular weight of water, for example, is 18 and hence 18 gm of water occupy a volume of 18 ml (or c.c.) and contain 6×10^{23}, the Avagadro number, of molecules. If the water molecules were cubic in shape such that they packed together without any gap, the volume of a single molecule would be $\frac{18}{6\times10^{23}}=3\times10^{-23}$ ml (or c.c.). If its shape is assumed spherical, the volume would be somewhat less, say, about 2×10^{23} ml. The volume of a sphere of radius r is $\frac{4}{3}\pi r^3$; hence the calculated radius would be about $1{\cdot}7\times10^{-8}$ cm, i.e., $1{\cdot}7\times10^{-10}$ m. This simple method produces a result of correct order of magnitude and provides an approximate indication of molecular and atomic dimensions.	one.
9. The negative charge associated with an atom is accounted for by the number of electrons which reside in the atom. The mass of an electron is very small compared to the mass of even the lightest of atoms and the question arises as to how the rest of the mass of the atom is distributed. If it is distributed uniformly throughout the atom, then it should occupy a spherical volume whose radius is about —— m.	10^{-10}
10. Re-read Item 9. It is also possible that the positive charge which balances the negative charge of the electron in an atom may be concentrated in a small volume inside the atom in a compact arrangement of mass and charge, called nucleus. In such a case we would expect the radius of the nucleus to be (less than /equal to/greater than) 1 ÅU.	less than
11. Items 9 and 10 throw up two different hypotheses regarding the structure of the atom. The notion that the positive charge in an atom is distributed uniformly in a sphere with a radius of 10^{-10} m was put forward	

STATEMENTS	CORRECT RESPONSE
by J. J. Thomson around 1900. The Thomson model is also known as 'plum-pudding' model of the atom. It can also be called 'water-melon' model because the electrons which neutralise the positive charge are supposed to be scattered around in the positive charge mass like the seeds in a water-melon (or like resins in a plum-pudding). According to Thomson the simplest atom, hydrogen, was to consist of a 'drop' of positive electricity about 10^{-10} m in radius in which the electrons were embedded. Thomson called this a sphere of positive electrification. Heavier atoms were supposed to contain a large number of electrons inside a large positive drop.	
In the Thomson model of the atom the positive charge carriers are uniformly distributed throughout the (atom as a whole/nucleus of the atom) and [(1) most of the atom is empty space/(2) all of the space in the atom is occupied by electrons and positive charge carriers].	atom as a whole (2)
12. Thomson's idea regarding the nature of the 'sphere of positive electrification' was rather (vague/convincing). His theory failed to explain the presence of limited number of electrons in heavy atoms. It is said that Thomson himself was not too well satisfied with this idea.	vague
13. In the early years of this century the Hungarian scientist, P. Lenard of 'Lenard ray' fame disputed Thomson's contention regarding uniform distribution of positive charges throughout the atom. He observed that swift cathode rays could penetrate sheets of aluminium and other metals. It appeared to him that a large portion of the atom was mostly empty. He thought of 'dynamids', a form of neutral doublet each consisting of a positive and a negative charge, accounting for the mass of the atom.	
There was another theory, published in 1904, by one Japanese physicist named H. Nagaoka. He compared the atom to the planet Saturn where stability is maintained by the attraction of the heavy central body on the lighter particles in the surrounding rings. He went on to argue that the atom could be approximately visualised if these satellites were replaced by negative	

STATEMENTS	CORRECT RESPONSE
electrons and the attracting centre by a positively charged particle. Unfortunately neither of the above speculation attracted any particular interest at that time. According to Lenard, space inside an atom is (mostly empty/fully occupied by charged particles).	mostly empty
According to Nagaoka negative charges in an atom move round the central positive charge particle like satellites round the planet Saturn. His proposition (was in agreement/did not agree) with that of Thomson.	did not agree
14. The hypothesis that the positive charge carriers in an atom are not uniformly distributed throughout the atom but are concentrated in a small region at its centre was advanced by Ernest Rutherford, a British scientist, and is called the 'nuclear' atom theory. The region in which the positive charge is concentrated is called the —— of the atom.	nucleus
15. Accordingly, the radius of the nucleus of an atom is (greater than/less than/equal to) the radius of the atom.	less than
16. The equation for the magnitude of the electric field at the surface of a sphere of radius R in which charge Q is uniformly distributed is given by the equation $E=k\cdot\frac{Q}{R^2}$. Assuming that Q remains unchanged, the magnitude of the electric field at the surface (increases/decreases/remains constant) as the radius of the sphere decreases. [Here k is a constant whose value depends on the system of units used in calculations].	increases
17. The magnitude of the electric field near the nucleus which carry the entire positive charge of the atom, is (stronger/weaker) than that near the surface of the atom.	stronger
18. We know from our study of electrostatics that positive charge attracts negative charge. In an atom if the positive nucleus is surrounded by negative electrons then the stability of the atom is affected. Due to electrostatic attraction of the nucleus electrons would collapse on to it. Atoms are remarkably stable and hence the above assumption was not complete. To prevent such a catastrophy Rutherford proposed that the electrons continuosly move round the nucleus ;	

STATEMENTS	CORRECT RESPONSE
the centripetal force required for such rotation is provided by the electrostatic force of attraction.	
In nuclear model of the atom the electrostatic force of attraction between the nucleus and the electrons does not cause the atom to collapse because —— —— —— (complete).	the electrons utilise this to generate the necessary centripetal force to rotate round the nucleus
19. According to Rutherford the central nucleus is positively charged. If a positive charge from outside is introduced inside an atom such that it approaches the nucleus it is likely that it will be (repelled/attracted) very strongly by the nucleus.	repelled
20. It appears likely that positively charged particles used as probes would be (able/unable) to disclose much information about the existence and the nature of the nucleus in an atom.	able
21. Nature has provided us with such convenient source of positively charged atomic probes in the form of particles emitted at high speed from certain substances (known as radioactive). We shall examine these materials in greater detail in Chapter viii. For the present we are only interested in the positively charged particles emitted from substances like radium with almost uniform speeds of about 10^7 m/sec. These (alpha, α) particles have a charge of 2 elementary charges and the mass of a helium atom minus its electrons (about $6{\cdot}7\times10^{-27}$ kg). The mass of a α-particle is about 8000 times the mass of an electron and it moves with high speed. This enables us to assume that its interaction with any electron in the atom it is used to probe will be negligible. Any change in the speed or direction of a α-particle as it passes through an atom is due to its interaction with the (positive/negative) charge.	positive
22. Alpha-particles from the same source have (widely varying speeds/approximately the same speed). All alpha-particles are (positively/negatively) charged and have masses which are (much greater than/much less than/equal to) the masses of electrons.	approximately the same speed ; positively much greater than

STATEMENTS	CORRECT RESPONSE
23. Examine the figure below. Alpha-particles are used to bombard a very thin gold foil. Gold can be rolled into a foil so thin that it is transparent to light.	



Thomson model which assumes uniform distribution of positive charges predicts the structure of the gold foil as shown. On bombardment by alpha-particles one or more of the following is/are most likely to happen. Can you point out ?

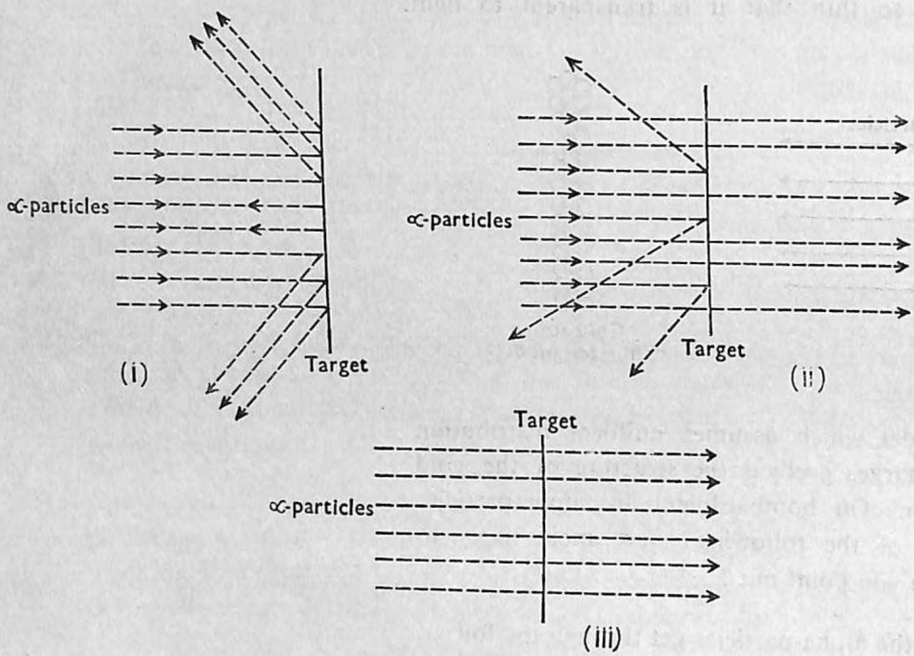
(1) None of the alpha-particles get through the foil.

(2) Some of the alpha-particles get through the foil whereas others are deflected back in the general direction from which they come.

(3) All alpha-particles get through the foil. (3)

24. Consideration of the magnitude of the electric field predicted for Thomson atoms and the high speed of the alpha-particles suggest that the bombardment of a thin gold foil in vacuum by alpha-particles is like firing '15-inch shell at a piece of tissue paper'. Which of the possibilities [(1)/(2)/(3)] of Item 23 is/are predicted by Thomson's theory ? (3)

STATEMENTS	CORRECT RESPONSE
25. If Thomson's theory is correct which figure [(i)/(ii)/(iii)] should predict the effect of bombarding a thin film of metal by alpha-particles ?	(iii)



26. Examine Fig. 5.2. This is a schematic diagram of an experimental setup used to study the structure of an atom. The results of the experiment will help us decide between Thomson's plum-pudding (or water-melon ?) and the nuclear hypotheses. There is a source of high speed alpha-particles (radioactive polonium) placed at a depth within a thick lead block to make the beam highly directional. The beam is directed towards a thin target which is surrounded by a fluorescent screen as shown. The screen emits point flashes at places where high speed charge particles strike it. The screen thus acts as an alpha-particle detector to show exactly how the paths of the incident particles are altered by interaction with atoms in the target. In this experiment a thin gold foil acts as the (source of ∝-particles/detector/target) ; some amount of polonium act as the (source of ∝-particles/detector/target) and the circular fluorescent screen acts as the (detector/target).	target source of ∝-particles detector

STATEMENTS	CORRECT RESPONSE
27. Fig. 5.2 and 5.3. The figures show what is actually observed when ∝-particles bombard a thin gold foil. Most ∝-particles pass through the foil either undeflected or slightly deflected from their original paths. This (is/is not) true of ∝-particles which follow the paths 2, 4 and 5 after interacting with the gold foil	is not
28. Thomson's atomic model predicts that (all/some/none) of the ∝-particles pass through the gold foil with slight deflections. Thomson's theory (predicts/does not predict) correctly the actual scattering observed in the experiment.	all does not predict
29. The above observations are generally true even if the source of alpha-particles or the target material or both are changed. The results therefore lead us to reject Thomson's hypothesis. It will be our interest to see if nuclear theory can account for the observed scattering	

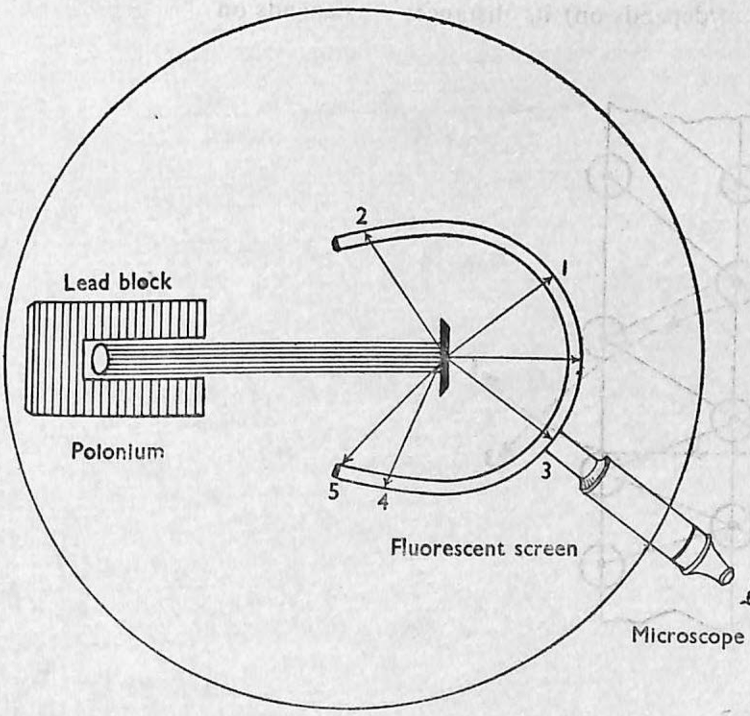


Fig. 5.2

∝-particle scattering device
Everything is enclosed in vacuum

STATEMENTS	CORRECT RESPONSE
of alpha-particles more adequately. Examine Fig. 5.4. Three different alpha-particles from the same source interacting with three different atoms in a target have been depicted here. The path of the incident alpha-particle is farthest from the centre of the nucleus in [(a)/(b)/(c)] ; it is closest to the centre of the nucleus in [(a)/(b)/(c)]. The angle θ between the direction of the incident alpha-particle and the scattered one (dashed line) measures the deflection produced in its path by the nuclear charge. The deflection is least when the distance d, between the centre of the nucleus and the initial path of the alpha-particle is (shortest/greatest). As d decreases θ (increases/decreases).	(a) (c) greatest increases
30. The greater the value of θ greater is the electric force of the nucleus on the alpha-particle. It is greatest in [(a)/(b)/(c)] when the alpha-particle is closest to the nucleus. The amount through which an alpha-particle is scattered (is independent of/depends on) its distance from the nucleus.	(c) depends on

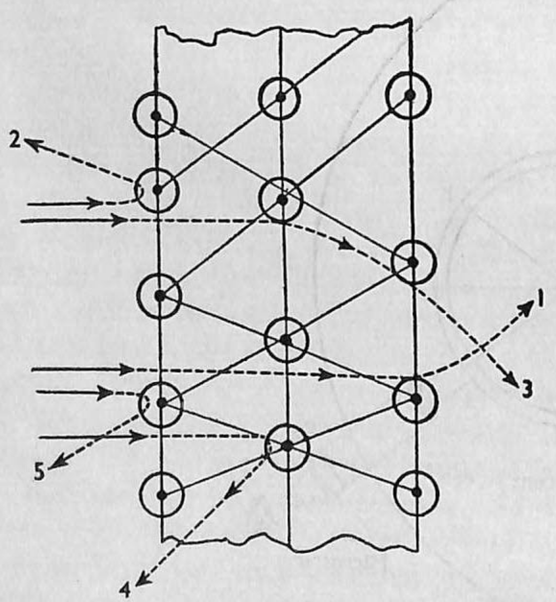


Fig. 5.3

Thin gold foil, about 3 atomic layer thick (magnified). The nucleus of each atom is shown with a black spot in the centre of the circle.

STATEMENTS	CORRECT RESPONSE
31. Refer to Fig. 5.2 and 5.3. The fact that most incident alpha-particles pass through the foil with little or no deflection means that they pass through atoms at relatively (large/small) distances from the nuclei. This suggests that the radius of an atom is (much greater/only slightly greater) than the radius of its nucleus.	large much greater
32. Refer Items 16–20. Smaller diameter of the nucleus makes its electric field near its surface (very strong/weak/very weak). The α-particles which are scattered to the points 2, 4 and 5 on the fluorescent screen are those whose paths are (close to/far from) the nuclei of gold atoms.	very strong close to
33. The large angle scattering of some α-particles by nuclei of the target (can/cannot) explained by Thomson hypothesis. Nuclear model speculated by Lord Rutherford (can/cannot) predict the occurrence of the above phenomenon correctly.	cannot can

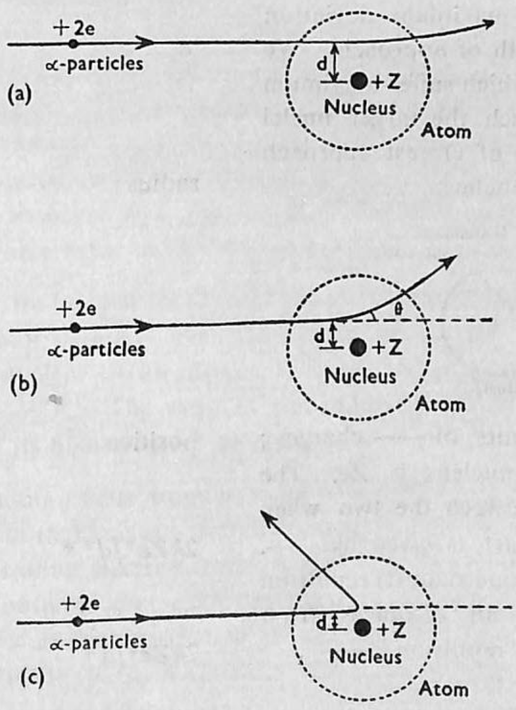
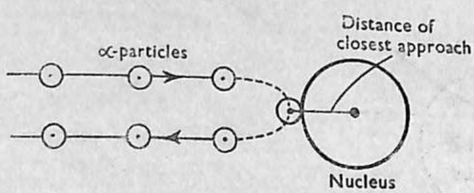


Fig. 5.4

STATEMENTS	CORRECT RESPONSE
34. According to Rutherford, closer does a α-particle approach an atomic nucleus the (greater/smaller) is the angle through which it is scattered (or deflected).	greater
35. Rutherford's calculations show that paths of the scattered particles are such as can be expected from the repelling forces associated with point charges, representing α-particles and nuclei. Nuclear charges of iron and gold are 26 and 79 respectively. Scattering of α-particles (from a given source) by an iron foil is (less than/greater than/same as) that by a gold foil of same thickness.	less than
36. When different metals are used as targets, the scattering of α-particles varies in such a way as to suggest that the nuclear charge of a metal is its atomic no. (Z) times the elementary charge, e i.e., Ze. The atomic number of silver is 47. The charge carried by the nucleus of silver is —— elementary charges.	47
37. Examine the figure below. It shows the path of a α-particle which reaches closer to a target nucleus than the others ; as a result it suffers maximum deviation due to repulsion back along the path of approach. We may conclude that the α-particles which suffer maximum scattering are those which approach the target nuclei closest. We can use this distance of closest approach to roughly estimate the —— of a nucleus.	radius



38. A single α-particle carries two units of —— charges ; the positive charge carried by a nucleus is Ze. The force of electrostatic repulsion between the two when their centres are at a distance d apart, is given by ——. The potential energy of (or work done against) repulsion is obtained by integrating over all distances from infinity to d. The result is : PE of repulsion = —— .	positive $2kZe^2/d^2$ * $2kZe^2/d$ *

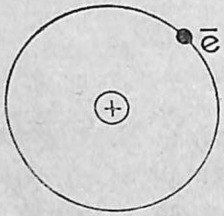
* Here k is a proportionality factor depending on the system of unit used in calculations.

STATEMENTS	CORRECT RESPONSE
39. Suppose a α-particle of mass m moving with a velocity v, and hence having a KE= ——, is approaching a nucleus for a head on collision as shown in item 37. As the particle gets closer the PE of repulsion ——, since d continually —— ; eventually at a point on its path the KE of the α-particle is exactly balanced by the PE of repulsion due to the nucleus. At this point called the ———— ——, the α-particle retards to rest momentarily and is then turned back.	$\frac{1}{2}mv^2$ increases decreases distance of closest approach
40. When the α-particle is at the distance of closest approach (d_0) from the centre of the nucleus, $\frac{1}{2}mv^2 = 2kZe^2/d_0$ Solve the above eqn. to obtain the value of d_0. d_0 is a rough estimate of the radius of the (atom/nucleus).	$4kZe^2/mv^2$ nucleus
41. Use the following data to estimate (only the order) the radius of the nucleus of a gold atom : $e = 10^{-19}$ C $v = 10^7$ m/s $m = 10^{-26}$ kg $k = 10^{10}$ N.m²/C² $Z = 79$.	$d_0 \sim 10^{-14}$ m
42. The distance of closest approach, found to be of the order of —— , represents a minimum value of the sum of the radii of a nucleus and an approaching α-particle. Since α-particle itself is the nucleus of —— atom, it is fair to estimate that the actual radius of a nucleus is somewhere between 10^{-14} m to 10^{-15} m.	10^{-14} m helium
43. Earlier we learned that the radius of an atom is about —— m or —— Å. We have just estimated the radius of the nucleus of an atom. It is of the order of —— m or —— Å. The ratio of the radius of an atom to that of its nucleus is of the order of —— .	10^{-10} 1 10^{-4} Å 10^4
44. The radius of an atom is more than 10000 times the radius of its nucleus. J. J. Thomson in 1881 calculated the size of an electron from its rest mass starting from the hypothesis that electrons mass is entirely electromagnetic in origin, that is to say, that the mass is due solely to the charge it carries. His equation was $$r = \frac{e^2}{mc^2}$$	

STATEMENTS	CORRECT RESPONSE
where, r is the radius of the electron, e is the charge of the electron, m is the rest mass of the electron and c is the velocity of light. Compute the radius of an electron from the standard values of the constants e, m and c.	$2{\cdot}82\times10^{-15}$m
45. The radius of an atom is about 10^{-10} m and it consists of a single central nucleus with a radius of the order of —— or less and a relatively small number of electrons, each of which has a radius of ——. It is obvious, therefore, that an atom must have a very 'empty' structure. Alpha-particle scattering indicates that the positive charge associated with an atom is [(1) evenly distributed throughout the atom / (2) concentrated in a very small portion of the atom].	10^{-14} m $2{\cdot}8\times10^{-15}$m (2)
46. The ratio of the radius of an atom to the radius of its nucleus is 10^4. The ratio of their volumes is the cube of this or —— (number). Electrons associated with an atom constitute an almost negligible part of its total volume as well as its mass although they account for all its —— ——. Alpha-particle scattering suggests that the mass of an atom is [(1) evenly distributed throughout its volume/(2) concentrated in a very small portion of the total volume of the atom].	10^{12} negative charge (2)
47. The nucleus occupies a volume which is one million millointh of the total volume of its atom. This means that (most/very little) of the atom is empty space and it accounts for the fact that most of the alpha-particles in Fig. 5.2 and 5.3 (are/are not) close enough to a nucleus to be deflected appreciably.	most are not
48. The maximum electric field in a Thomson atom can be computed and is of the order of 10^{13} Newton/Coulomb. The maximum electric field in a nuclear model atom, i.e., near the surface of the nucleus is about 10^{21} Newton/Coulomb. The maximum electric force exerted on an alpha-particle by a nuclear atom is —— times the maximum force exerted by a Thomson atom.	10^8
49. Note Item 48. In an actual experiment of alpha-particle scattering by an atom, (a few/large number) of the bombarding particle are scattered because —— —— pass close enough to the nucleus of the atom to be very	a few very few

STATEMENTS	CORRECT RESPONSE
strongly deflected. This suggests that scattering is much more likely to occur in an atom which has the structure assumed in the (Thomson/Rutherford) hypothesis.	Rutherford
50. The (Thomson/nuclear) model of the atom can adequately explain the rationale of the observed alpha-particle scattering.	nuclear
51. The nuclear hypothesis about the structure of the atom was first speculated by Earnest Rutherford (1912) who headed the team which carried out and interpreted the first alpha-particle scattering experiment. It is also called the solar system atom, since the concentration of the mass in a nucleus near the centre surrounded by electrons in circular or elliptical orbits is remeniscent of the sun-planet system. Re-read Item 13. The proposed picture of the atom put forward by Rutherford was not essentially different from the 'Saturn atom' of Nagoaka. Nevertheless, Rutherford is invariably given credit for originating the nuclear atom because he made the nuclear atom 'efficient in the stream of science'. Actually, the differences between the solar system or the saturn system and the nuclear atom are much more scientifically significant than their similarities. The force which holds the planets (or satellites) in their orbits is (electrical/gravitational); the force which holds electrons in their orbits is (electrical/gravitational).	gravitational electrical
52. The Rutherford model of the atom visualised a highly concentrated mass which practically accounts for the entire mass of the atom carrying a (positive/negative) charge and called the —— surrounding which (positive /negative) charge carriers called —— rotate.	positive nucleus negative ; electrons
53. The magnitude of the positive charge residing in the nucleus of an atom of a given element is always (less than/greater than/equal to) the product of the atomic number of the element and one electronic charge. The total negative charge carried by all the electrons of an atom is always (less than/greater than/equal to) the positive charge in the nucleus.	equal to equal to
54. Refer to Table 4. The lightest stable element is hydrogen and the heaviest one is lead. The nucleus of a hydrogen atom carries —— elementary positive	one

STATEMENTS	CORRECT RERPONSE
charge (s) or —— C of positive charge. A hydrogen atom has —— electron (s).	$1{\cdot}6 \times 10^{-19}$ one
55. Refer to Table 4. The nucleus of a lead atom carries positive charge equivalent of —— elementary charge(s). It is surrounded by —— electrons.	82 82
56. The adjoining figure represents the Rutherford model of the atom of —— .	hydrogen



57. When a hydrogen atom looses its electron, the particle which remains is called a proton. A proton has an electrical charge of (1/·01) elementary charge. The mass of a proton is about (2/200/2000) times the mass of an electron.	1 2000
58. Recall item 53. Protons are positive charge carriers in atoms. The atomic number of oxygen is ——. The number of protons in the nucleus of an atom of oxygen is ——.	8 8
59. Experiments performed later on to verify Rutherford's α-particle scattering results suggested that the no. of positive charges carried by the nucleus of an atom could approximately be half of its atomic weight (the only exception being the hydrogen atom). Positive charge carried by the nucleus of an oxygen atom is 8 elementary charges. Its atomic weight could be ——.	16
60. Experiments show that except for the hydrogen atom, protons (do/do not) account for the entire mass of a nucleus. The total charge carried by the protons, on the other hand, (does/does not) account for the entire charge of a nucleus.	do not does

NOTES

(1) Rutherford's atomic model was a distinct improvement over the Thomson's one. It did away with the vague 'sphere of uniform positive electrification'

STATEMENTS | **CORRECT RESPONSE**

of Thomson. The charge distribution in an atom between the orbital electrons and the nucleus, as envisaged in the model, could correctly account for the electrical neutrality of an atom. However, the 'mass gap' it had left led to massive neutron hunt to account for the total mass of the atom.

(2) Which of the following statements are true ?

(i) The electrons of an atom account for most of its mass.

(ii) The force responsible for α-particle scattering in a solar system atom is gravitational.

(iii) The protons in the nucleus of an atom account for all of its positive charge.

(iv) The ratio of the size of an atom to its nucleus is comparable to that of the earth's orbit to the size of the sun.

(v) The number of protons in the nucleus of an atom is generally about half its atomic weight.

Correct response: (iii), (iv), (v)

(3) Compute the distance of closest approach of a α-particle of energy 5 MeV to a nucleus of copper in a α-scattering experiment.

Correct response: $1{\cdot}9\times10^{-14}$m

VI

Atomic Spectra

Spectral Series of Hydrogen

Test of any hypothesis lies in its ability to explain observed phenomena. The Rutherford model of the atom, also known as the nuclear or solar system model, provides a reasonable explanation of the α-particle scattering by the atoms of metal foils. We next consider whether the model can adequately explain the spectra of different substances we observe. In fact, a great deal of information about the arrangement of electrons surrounding atomic nuclei has been gathered from the study of atomic spectra. When a substance is heated sufficiently in a flame or by means of an electric arc or spark, or, if it is gaseous, an electric discharge is passed through it, radiation, mainly in the visible and ultra-violet regions is often emitted. If the rays are examined in a spectroscope, which is an instrument for splitting up complex radiation into its components of different wavelengths or frequencies, a definite pattern of lines, called spectrum, appears. This spectrum is characteristic of the element or elements present in the material emitting the radiation and is usually known as the atomic spectrum of the heated substance. This is because the radation originates in the atoms of the element or elements present in it. The lighter atoms, such as hydrogen or helium, yield fairly simple spectra with relatively small number of lines, while for some of the heavier atoms the spectra may consist of hundreds of lines. In this section we will examine in detail the simplest of these spectra and indicate how it might be accounted for by our knowledge about the structure of atoms.

STATEMENTS	CORRECT RESPONSE
1. It is well-known that when white light passes through a prism, the former is dispersed into its seven constituent colours, each colour having its own particular frequency. We know that radiation (including light) which consists of electromagnetic waves of more than one frequency is called (monochromatic/polychromatic).	polychromatic
White light consists of electromagnetic radiation of (one frequency /many different frequencies).	many different frequencies
For this reason, white light is said to be (monochromatic/polychromatic).	polychromatic

STATEMENTS	CORRECT RESPOSE
2. Dispersion of white light into its constituent monochromatic colours results in the formation of a continuum of colour ranging from red on one end through orange, yellow, green, blue and indigo to a deep violet on the other hand. All these colours in the continuum correspond to (different frequencies/same frequency). The continuum so formed is known as visible spectrum.	different frequencies
3. The classification of electromagnetic waves according to their frequencies is known as electromagnetic spectrum. Refer to Fig. 1·2 (Chapter I). The visible continuum of colours produced when light passes through a dispersive medium (is/is not) part of this classification.	is
4. Which of the following is/are not part of the visible spectrum : (infrared radiation/green light/yellow light /ultraviolet radiation) ? The visible spectrum constitutes (all/some) of the electromagnetic spectrum.	infrared radiation ; ultraviolet radiation; some
5. The range of observed frequencies in the electromagnetic spectrum is from zero to about 10^{25} Hertz (or cycles per sec). The portion which is known as visible lies between 4×10^{14} Hz to 8×10^{14} Hz. The visible spectrum is a (large/very small) part of the e.m. spectrum.	very small
6. From our study of optics we know that an incandescent solid, liquid or gas at high pressure produces a visible spectrum which is a continuous band of colour representing electromagnetic waves of (one frequency /many frequencies/a few frequencies). This type of spectrum is called an emission spectrum.	many frequencies
7. When a gas is made to glow under high pressure, its spectrum (is/is not) continuous. When a gas at low or moderate pressure is made to glow, it produces an emission spectrum which consists of one or more bright coloured lines on a dark background.	is
8. The spectrum of an incandescent solid or liquid is a (continuous/bright line) spectrum. The spectrum of a gas which is incandescent and at low pressure is a (continuous/bright line) spectrum. In general, fewer the frequencies the less complicated is the spectrum. The spectrum of an incandescent solid is (more/less) complicated than that of an incandescent gas at low pressure.	continuous; bright line; more

STATEMENTS	CORRECT RESPONSE
9. Fig. 6.1 [(a)/(b)/(c)] is a bright line spectrum. Fig. (c) (could/could not) be the spectrum of a glowing gas at low pressure.	(c) could

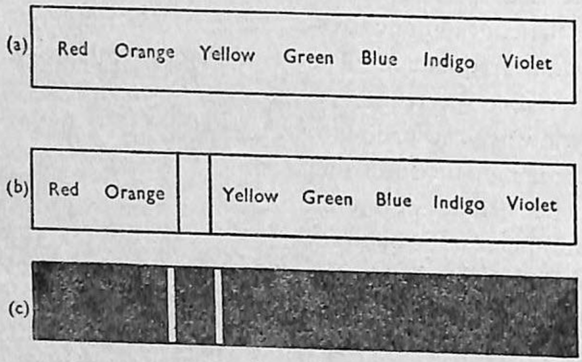
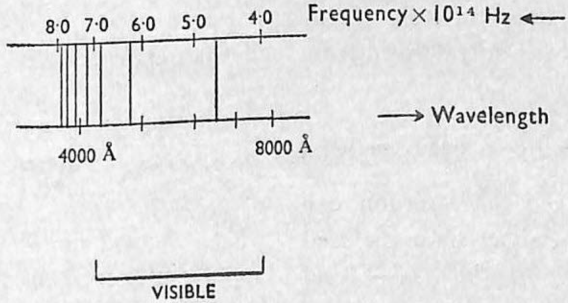


Fig. 6.1

10. It should be known to the reader that the atoms of solids and liquids are much more likely to interact with each other than the atoms in gases because in the former the inter-atomic distances are (smaller/greater). To understand atomic structure from the study of atomic spectra, it is advisable to avoid complicated interactions between atoms. It is best to study spectra of a substance in its (solid/liquid/gaseous) state.	smaller gaseous
11. The atoms of a gas under low pressure are (closer together/farther apart) than when under high pressure. We are more likely to avoid complications due to interacting molecules and atoms if we study a gas at (low/high) pressure.	farther apart low
12. To study the internal structure of an atom and not its interactions with other atoms, it is best to analyse the spectra of samples of various elementary substances. The spectra, we are most interested in for this purpose, are (continuous/bright line) spectra because such spectra are less likely to suffer from interactions between atoms.	bright line
13. Of all the elements hydrogen has the smallest mass and has only one orbital electron. Its nuclear charge is ......elementary charge. Hydrogen atom is structurally very simple. The visible spectrum of hydrogen, shown in Fig. 6.2, is (continuous/bright line) spectrum.	one bright line

STATEMENTS	CORRECT RESPONSE
14. Examine Fig. 6.2. The visible spectrum of hydrogen consists of a series of bright lines which get closer together as we move from (lower/higher) to (lower/higher) wavelengths. The bright line at the higher wavelength end of this spectrum is —— (colour) and has the frequency ——.	higher lower red $4{\cdot}6\times10^{14}$ Hz
15. Balmer was a Swiss school teacher, more interested in number games than physics. He observed that the lines in the visible spectrum of hydrogen form a series. It is obvious that as we move from higher to lower wavelengths, i.e., from lower to higher frequencies, these lines (converge/diverge).	converge
16. Balmer arranged a sequence which was a mathematical model for predicting the exact positions of the bright lines in the hydrogen spectrum. The present form of this equation is : $$\nu=R\left(\frac{1}{n_f^2}-\frac{1}{n_i^2}\right)$$ in which $R=3{,}29\times10^{15}$ per sec $n_f=2$ and $n_i=$ any whole number greater than 2 The series of bright lines which constitutes the visible spectrum of hydrogen became famous as Balmer series in course of time. The frequencies computed for $n_i=3$, $n_i=4$ and $n_i=5$ are ——, ——, and —— Hz respectively.	$4{\cdot}57\times10^{14}$; $6{\cdot}17\times10^{14}$; $6{\cdot}9\times10^{14}$
Is there a bright line corresponding to $\nu=5{\cdot}5\times10^{14}$ Hz in the Balmer series of hydrogen ? (Yes/No).	No



The visible spectrum of hydrogen

Fig. 6.2

Notice how the lines crowed around in the high frequency region

STATEMENTS	CORRECT RESPONSE
17. Refer to Fig. 6.2. Balmer series represent the series of bright lines in the visible emission spectrum of hydrogen. The mathematical model for computing the frequencies of the lines which appear in the series is ν=—— (complete), where R=——, n_f is the fixed number —— and n_i is any (number/whole number) (greater than/less than) n_f	$R\left(\frac{1}{n_f^2}-\frac{1}{n_i^2}\right)$; $3{\cdot}29\times10^{15}/s$ 2 ; whole number greater than
18. When the value of n_i approaches infinity, the limit to which Balmer series converges is reached. When $n_i \rightarrow \infty$, the equation for ν reduces to ν=——. Compute the value of $\frac{R}{n_f^2}$ for the Balmer series. This value is the series limit for the series. (All/some/none) of the bright lines in the visible spectrum of hydrogen have frequencies less than this limiting value. What is the corresponding wavelength ?	$\frac{R}{n_f^2}$, $8{\cdot}23\times10^{14}$ Hz All $0{\cdot}3636\times10^{-6}$ m (or 3636 Å)
19. The reader should note here that the equation for the Balmer series was not derived from any physical principle although it could successfully predict the frequencies of the bright lines in the visible spectrum of hydrogen. Balmer merely used algebric tricks to produce a model which could predict the position of any line in the spectrum ; Fig. 6.2. The wavelengths and frequencies of the first four lines correspond to n_i=3, 4, 5 and 6 in the formula. What is the frequency of the fifth bright line in the Balmer series ?	Putting $n_i=7$, $\nu=7{\cdot}55\times10^{14}$ Hz
20. $\nu=R\left(\frac{1}{n_f^2}-\frac{1}{n_i^2}\right)$. The equation can successfully predict the frequencies of the bright lines in the visible spectrum of hydrogen. It (was/was not) derived from any physical principle.	was not
21. $\nu=R\left(\frac{1}{n_f^2}-\frac{1}{n_i^2}\right)$. It will be interesting to examine what other observable series of hydrogen the equation can generate if n_f=3 or n_f=1. For Balmer series we used the formula with $R=3{\cdot}29\times10^{15}/s$, n_f=—— and n_i=(1, 2, 3, etc./2, 3, 4, etc./3, 4, 5, etc.).	2 3, 4, 5, etc.
22. We put $n_f=3$ and $n_i=4$, 5, 6 etc. The first line in this new series should have the frequency —— or wavelength ——.	$1{\cdot}60\times10^{14}$ Hz 18758 Å

STATEMENTS	CORRECT RESPONSE
23. $\nu = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$. When $n_f = 3$ and $n_i = 4$, the frequency expected is —— Hz ; this is (above/below) the frequency range of the visible spectrum and falls in the (infrared /ultraviolet) part of the spectrum.	$1{\cdot}60 \times 10^{14}$ Hz ; below infrared
24. Lines in the infrared region are not visible ; however, they can be photographed. Compute the frequencies and the corresponding wavelengths of three more lines in the infrared region by putting $n_f =$ —— and $n_i = 5$, 6 and 7.	3 Frequencies are : $2{\cdot}34 \times 10^{14}$ Hz ; $2{\cdot}74 \times 10^{14}$ Hz ; $2{\cdot}98 \times 10^{14}$ Hz Wavelengths are : 12823 Å ; 10942 Å ; 10053 Å
25. Re-read item 18. We compute the limit of this series by calculating ν when $n_f = 3$ and $n_i =$ —— . The value of ν as computed is —— . The corresponding wave-length is —— .	∞ $3{\cdot}66 \times 10^{14}$Hz 8207 Å
26. Refer Fig. 6.3. It is the experimentally observed spec-turm of hydrogen and contains the specturm in both the infrared and visible regions. The predictions regarding the infrared spectrum of hydrogen (agree/do not agree) with experimental results. The spectral series in the visible spectrum is called the —— series.	agree Balmer

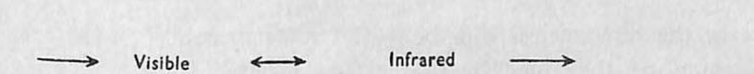


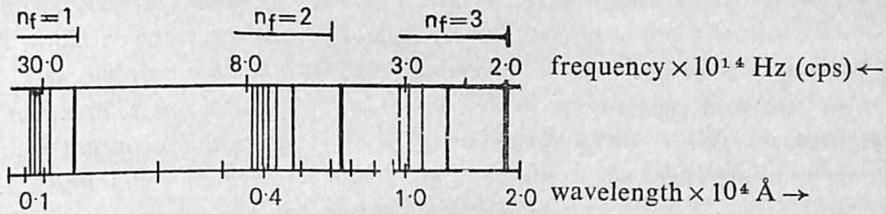
Fig. 6.3

Emission lines in the visible region can be computed from the spectral series equation when $n_f = 2$ and n_i is any whole number greater than 2

Emission lines in the infrared region can be computed by putting $n_f = 3$ and $n_i > 3$

STATEMENTS	CORRECT RESPONSE
The frequencies and the wavelengths of these lines can be computed by putting n_f —— and n_i ——.	2 ; 3, 4, 5, etc.
The spectral series in the infrared is known as Paschen series. The frequencies and the wavelengths of these lines can be computed when the number —— is substituted for n_f	3
and the whole numbers beginning with —— are substituted for n_i in the equation $\nu=R\left(\frac{1}{{n_f}^2}-\frac{1}{{n_i}^2}\right)$, called the spectral series equation.	4
27. The spectral series equation first derived by Balmer (from physical principles/as a mathematical model)	as a mathematical model
enables us to predict the positions of the bright lines in the visible spectrum when (n_f/R/n_i)=3, 4, 5, etc., and	n_i
(n_f/R/n_i)=2. It also enables us to compute the frequencies and thus know the positions of the lines in the	n_f
infrared spectrum when (n_f/R/n_i)=4, 5, 6, etc., and	n_i
(n_f/R/n_i)=3.	n_f
28. We recapitulate. We have seen that hydrogen gas when made to glow produces (continuous/bright line)	bright lines
spectra in the visible and infrared regions of the e. m. spectrum. (Only one/both/neither) of these can be	both
accurately predicted by the spectral series equation, $\nu=$——	$R\left(\frac{1}{{n_f}^2}-\frac{1}{{n_i}^2}\right)$
29. Substituting the value of $n_f=2$, $n_i=3$, 4, 5, etc., we can compute the positions of the lines in the visible spectrum from the spectral series equation. Substituting the value of $n_f=3$, $n_i=4$, 5, 6, etc., we can compute the positions of the lines in the infrared spectrum. It is tempting, therefore, to check what happens when $n_f=1$ and $n_i=2$, 3, 4, etc. It is obvious that as n_f decreases $R\left(\frac{1}{{n_f}^2}-\frac{1}{{n_i}^2}\right)$ (increases/decreases).	increases
30. The frequency of the lines in the new series will be (greater/less) than the frequency of the lines in the	greater
visible spectrum. The new series which is to the (left/right) of the visible spectrum, Fig. 6.3, occupy	left
that portion of the electromagnetic spectrum called —— region.	ultraviolet
31. Refer to Fig. 6.4. This shows the experimentally observed spectra of luminous hydrogen gas in the infrared, visible and ultraviolet regions. The spectral series in	

STATEMENTS	CORRECT RESPONSE
the infrared region is called —— ——, that in the visible region is called —— —— and the series in the ultraviolet region is called —— ——.	Paschen series Barmer series Lyman series
32. Compute the frequency and wavelength of the first line in the Lyman series and also calculate the series limit by using the formula : $\nu_{\text{series limit}}$=——.	$2{\cdot}47 \times 10^{15}$ Hz 1200 Å R/n_f^2 $3{\cdot}29 \times 10^{15}$ Hz (or 900 Å)
33. The positions of the observed lines in the ultraviolet region (agree/do not agree) with the theoretical prediction. Spectral series equation (is/is not) a good mathematical model for predicting the emission spectrum of luminous hydrogen gas. It (was/was not) derived from any physical principle.	agree is was not



$n_f=1$; Lyman series in the ultraviolet region
$n_f=2$; Balmar series in the visible region
$n_f=3$; Paschen series in the infrared region

Fig. 6.4

NOTE :

STATEMENTS	CORRECT RESPONSE
(a) The success of the spectral series equation in predicting the emission spectrum of hydrogen led us to accept it as a (good mathematical model /fundamental equation) for describing the phenomena.	good mathematical model
(b) Which of the following are true ?	
(i) Luminous hydrogen gas at ordinary pressure produce bright line spectrum.	
(ii) Any incandescent solid produce bright line spectrum.	
(iii) The Paschen series is a bright line spectrum in the visible region.	
(iv) The Balmer series is a bright line spectrum in the visible region.	

STATEMENTS		CORRECT RESPONSE
(v)	The spectral series equation has been derived from Rutherford's atomic model	
(vi)	Bright lines on dark background are emmission spectrum of luminous gas at low or moderate pressure.	
(vii)	Theory which help derive spectral series equation should be a correct theory.	
(viii)	Bright line spectra are better than continuous spectra for studing the internal structure of the atom.	
(ix)	Interatomic distances in solids and liquids are less than those in gases.	
(x)	Light of wavelength lying between 4000 Å to 8000 Å fall in the visible region.	(i) ; (iv) ; (vi) ; (vii) ; (viii) (ix) ; (x)

VII

Bohr's Theory of Hydrogen Atom

The success of the spectral series equation in predicting the behaviour of luminous hydrogen gas so far as its emission spectrum is concerned, indicated the possible existence of a general underlying principle. If we assume that the spectral series of any element is due, to a large extent, to a definite structure of the atoms of the element then any successful theory of atomic structure must enable us to derive an expression which would be equivalent to the spectral series equation.

The question we have to examine here is : how can we account for the bright line spectra in terms of atomic structure ? More specifically, how can we account for the bright line spectrum of luminous hydrogen gas in terms of the structure of hydrogen atom ? Any theory we develop about the structure of the hydrogen atom should enable us to derive the spectral series formula.

According to Maxwell's classical electromagnetic theory, the emission of radiation, such as the characteristic spectrum of an element is due to some oscillating electrical systems. Side by side with the growth of the concept of electron as the unit of charge, there was the parallel development of the idea that the line spectra were related to vibrating electronic charges within the atom. Suggestions of this kind were made in the early 1890s by several scientists, including G. J. Stoney, G. F. Fitzgerald, H. Eber and, in particular, J. Larmor (1894) and H. A. Lorentz (1895) who also treated the mathematical aspects of the problem in some detail.

In 1904 Nagaoka proposed his 'saturn' atom and suggested that atomic spectra might be due to "the oscillatory motion of the electrons revolving in circular orbits". But this view was untenable. To account for the fact that the orbital electrons did not fall into the nucleus as a result of electrical attraction, Rutherford found it necessary to postulate a rapid rotation of these electrons round the nucleus, somewhat similar to the rotation of the planets round the sun. The inward attractive force was supposed to be balanced by the outward centrifugal reaction. The analogy between an atom and the planatery system was misleading because the particles within an atom are electrically charged. According to the electromagnetic theory, as mentioned above, every rotating electron should continuously radiate energy during its motion. If it were so, the radius of curvature of its orbit would steadily diminish due to gradual depletion of energy by radiation. As a result the electron would follow a spiral path and eventually collapse into the nucleus. This would make the atom a highly unstable entity, which is contrary

to our experience. Further, if the emission spectrum were related to the energy radiation of a rotating electron, it would be continuously changing with the diminishing radius of the electron path. Atomic spectra would, therefore, cover a continuous range of wavelengths instead of being consisted of some well-defined lines.

To overcome this apparent contradictions Neils Bohr in 1913 enunciated a unique theory of atomic structure. It was novel in the sense that many notions he introduced were not in conformity with the then prevailing laws of physics, now referred to as classical laws. In this chapter the reader will go through a through discussion pinpointing the weakness of Rutherford's atomic theory and on the gradual development of the logic of Bohr's theory. He is advised to read this introduction carefully before going through the following programme.

STATEMENTS	CORRECT RESPONSE
1. The classical theory of e.m. waves proposes their production to the acceleration of —— ——. Radio waves are produced when —— are forced up and down an antenna in simple harmonic motion, which (is/is not) a type of accelerated motion. Radio waves (are/are not) electromagnetic waves.	charged particles electrons is are
2. According to classical theory when an accelerating charged particle emits e.m. waves it loses energy. If the electrons in an antenna are not supplied energy from outside to replenish the e.m. energy they emit, the electrons (continue/cease) to accelerate and (continue /cease) to emit e.m. waves.	cease cease
3. Analysis of cavity radiation by Planck led him to introduce the quantum theory of electromagnetic radiation. (Classical/quantum) theory of e.m. radiation is not always completely consistent with observed phenomena.	Classical
4. Bright line emission spectrum of hydrogen is a classification of emitted electromagnetic waves in terms of their frequencies or wavelengths. The characteristic bright line spectra in general and the spectral series of hydrogen in particular consist of (all/none/only some) of the possible frequencies of the e.m. spectrum. They (are/are not) continuous.	only some are not
5. It will be interesting to examine if Rutherford atom and the classical theory of e.m. radiation can help explain the occurrence of the observed bright line spectra of hydrogen. According to classical theory, the emission of infrared, visible and ultraviolet	

STATEMENTS	CORRECT RESPONSE
radiation from luminous hydrogen is due to —— of —— —— in the hydrogen atom. The frequency of each emission line is equal to the frequency of rotation of the corresponding electron in its orbit.	acceleration charged particle
6. According to Rutherford theory, an atom of hydrogen consists of a single proton in the nucleus around which a single electron revolves like a planet round the sun. Rutherford postulated the rapid rotation of electron round the nucleus to account for the stability of electrons against the attractive electrostatic force of the ——.	proton
The electron follows a curved path and thus is (always /sometime/never) accelerating. Can you compute the energy of the electron in the hydrogen atom ?	always

Soln. :

The force of attraction between the electron and the proton follows Coulomb's law. It can be shown from classical mechanics that the resultant close path will be circle or an ellipse under the action of such a force. We assume, therefore, that the orbit of the electron in the solar system model of the atom is a circle of radius r, the nucleus being supposed fixed in space.

The force of attraction between the nucleus (i.e., the proton) and the electron is ke^2/r^2 newton, where k is a constant.* The centrifugal force on the electron revolving with a velocity v is mv^2/r. Following Newtonian mechanics,

$$\frac{ke^2}{r^2}=\frac{mv^2}{r} \quad \text{or} \quad \frac{ke^2}{2r}=\frac{1}{2}mv^2$$

The potential energy of the electron at a distance r from the nucleus is $-\frac{ke^2}{r}$; its kinetic energy is $\frac{1}{2}mv^2$. Following the law of conservation of energy, the total energy W of the electron is,

$$W=\tfrac{1}{2}mv^2-ke^2/r=ke^2/2r-ke^2/r,$$

$$\text{or} \quad W=-\frac{ke^2}{2r}$$

The equation shows that the total energy of the electron is always considered negative and that the energy of the

* Refer to item 38, Ch. V.

STATEMENTS	CORRECT RESPONSE
electron at a infinite distance from the nucleus is zero. Hence when the electron approaches closer to the nucleus the energy of the electron becomes more negative i.e., it decreases.	
7. If the electron of the hydrogen atom is always accelerating then, following classical rule, the atom must (always/sometime/never) emit electromagnetic radiation.	always
8. But if the atom is always emitting electromagnetic radiation its electrons must always be losing energy and get continually (closer to/further from) the nucleus if no energy from outside replenishes this loss.	closer to
9. An electron in a Rutherford (i. e., solar system) atom should, according to classical argument, spiral into the nucleus if no energy is supplied from outside from an extra-electronic or extra-atomic source. It can be shown that this collapse ought to take place in a very small fraction of a second. On the contrary we observe a marked stability of electrons in their orbits even though no energy enters the atom. This observed phenomena (is/is not) consistent with classical theory.	is not
10. Read introduction to this chapter carefully. Another prediction of the classical e.m. theory and Rutherford's solar system model for an atom is that atomic spectrum should be a continuous one because the energy radiated by the orbiting electron would be changing as the radius of curvature of its path continually (increases/decreases) with time. This prediction (is/is not) consistent with the bright line spectra characteristic of hydrogen.	decreases ; is not
11. We summerise. The classical theory predicts that whenever a charged particle is accelerated it emits electromagnetic radiation. If we assume that an electron in an atom must always be orbiting round the nucleus to account for the unbalanced electrostatic force between the nucleus and the electron, then the atom should (never/always/sometimes) emit radiation.	always
12. We know that only glowing hydrogen gas emits radiation. That is, for emitting radiation every hydrogen atom has to be energised by supplying energy by some means from outside. The classical theory could possibly be retrieved from this helpless situation if we	

STATEMENTS	CORRECT RESPONSE
were allowed to assume that the electron in a hydrogen atom is at rest. But are we allowed to do so? There (is no/is an) unbalanced electrostatic force in an atom. An electron (can/cannot) be at rest in a hydrogen atom and for that matter, in any atom.	is an cannot
13. Recall your study of photoelectric emission. Light consists of streams of photons. Each bright line in the spectrum of hydrogen represents electromagnetic waves of a single frequency. Each line is made by stream of photons having (the same energy/different energy).	the same energy
14. The nature of the spectral series of hydrogen indicates that the energy emitted by the hydrogen atom is not continuous. They are quantised. Recall that Planck assumed the energy emitted by the oscillators in a cavity radiator as (continuous/quantised). This observation (is/is not) in agreement with classical theory of e.m. radiation.	quantised is not
15. To salvage the classical theory and to overcome its contradictions Neils Bohr, then working in Rutherford's Manchester laboratory, made (1913) the surprising suggestion that the electron in a hydrogen atom does not radiate energy while it is moving in a closed orbit. This was to account for the fact that hydrogen atom does not emit e.m. radiation continuously. This suggestion was (in accordance with/contrary to) the requirements of classical theory.	contrary to
16. Bohr's suggestion led him to attribute stability to an electron's orbit. An electron in a stable orbit represents a 'stationary state' of the atom. Several such stationary states were assumed possible for an atom. Each stationary state corresponds to, what Bohr called, the allowable orbit for an electron of the atom. While an electron is in any one of these —— the atom (does/does not) radiate energy.	orbits does not
17. According to Bohr the energy of a hydrogen atom is constant in each stationary state; but it differs from state to state. How can the lines in the spectral series be produced then? The production of a spectral line of definite frequency was attributed to the radiation of energy associated with the transition of an electron from a state of higher	

STATEMENTS | **CORRECT RESPONSE**

energy to one of lower energy, the frequency (or wavelength) being related to the energy change by means of the quantum theory equation, $E=h\nu$.

18. Read item 17. Hydrogen atom emits a photon whenever its electron changes from one allowable orbit with —— energy to an orbit with —— energy. Reread item 6. The electron in an orbit with larger radius has greater energy. When hydrogen atom emits radiation the orbital radius of its electron (decreases/increases).

    higher ; lower

    decreases

19. Refer Fig. 7.1. According to Bohr this atom emits radiation when [(i) it is in orbit with radius r_2/ (ii) It is in orbit with radius r_1/ (iii) it changes from the orbit with radius r_1 to the orbit with radius r_2/ (iv) it changes from the orbit with radius r_2 to the orbit with radius r_1].

    (iv)

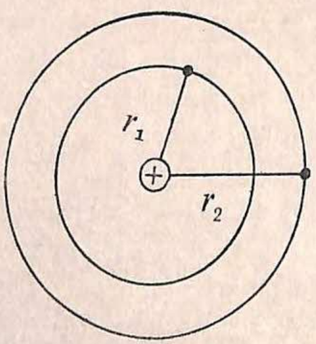
20. Fig. 7.1. When the atom is in the stationary state with the electron in the allowable orbit of radius r_1, it (emits/does not emit) e.m. radiation. When the electron is in the allowed orbit with radius r_2, the atom (emits/does not emit) e.m. radiation. When the electron changes its orbit from one with radius r_2 to one with radius r_1, the atom (emits/absorbs) energy. When the electron changes its orbit in the reverse direction i.e. from one with radius r_1 to one with radius r_2, the atom should (emit/absorb) energy.

    does not emit

    does not emit

    emits

    absorb



Schematic view of a hydrogen atom in two different stationary states. Each full circle surrounding the nucleus represents one of the states.

Fig. 7.1

STATEMENTS	CORRECT RESPONSE
21. According to quantum theory emission of e.m. radiation means emission of photons. When the electron in a hydrogen atom moves down from a higher energy state to a lower energy state, —— having energy equal to the energy difference between the states are ——.	photons emitted
22. To account for the electron transfer, called transition, from one allowable orbit to another in a finite time ($\sim 10^{-9}$ sec) without passing through intermediate energy states which, otherwise, would result in emitting continuous spectrum, Bohr introduced the idea of 'jump' suggesting that the transition from one state to another (is/is not) continuous.	is not
23. We conclude that the electron (does/does not) pass through a series of intermediate orbits because the radiation emitted during one of these changes is (continuous/quantised) as the observed spectral series indicate.	does not quantised
24. The (abrupt/smooth) change of an electron from one allowed orbit to another is called —— ——.	abrupt quantum jump
25. Applied to the electron as a particle, this notion of a quantum jump without a smooth continuous transition through intermediate orbits in a spiral fashion is difficult to conceive. As a general rule particles do not behave in this manner. Recall your study of wave-matter hypothesis, (Chapter IV) ; Bohr's Principle of Complementarity suggests that when the particle aspect of matter fails to explain certain observations we use the —— aspect of matter to explain these observations.	wave
26. Electrons (have/do not have) waves associated with them.	have
27. Photon which carries electromagnetic energy equal to the energy difference when an electron jumps from a higher orbit to a —— one (has/does not have) particle characteristics. Energy emitted in the form of electromagnetic radiation is therefore considered ——.	lower ; has quantised
28. The concept of quantisation of energy in case of emission as well as absorption is consistent with (classical /quantum) theory of radiation. It was introduced to physics by (Planck/Thomson/de Broglie), developed further by (Einstein/Davisson/Lorentz) and fully established by (Compton/Rutherford/Balmer). According to quantum theory radiations are emitted, transported	quantum Planck Einstein Compton

STATEMENTS	CORRECT RESPONSE
through space and absorbed as energy particles called ——.	photons
29. If E_i be the energy of an atom in a state of higher energy (initial state) and E_f that in a state of lower energy (final state), then an electronic transition from the former to the latter state will be accompanied by the emission of energy = —— (complete). Compute the frequency and wavelength of the associated photon for quantum theory.	$(E_i - E_f)$; $\nu = \frac{E_i - E_f}{h}$; $\lambda = \frac{c}{\nu} = \frac{ch}{E_i - E_f}$
30. If hydrogen gas is exposed to conditions under which the absorption of energy is possible e.g. by the use of high temperature or a suitable electrical discharge, the electrons which are normally in their lowest energy state (called ground state) are pressumed to take up energy and pass into states of higher energy. These higher energy states are known as excited state of the atom. The spontaneous return of the electrons ($\sim 10^{-9}$ sec) from higher to the lower states should result in liberation of specific amount of energy, each such transition giving a line of definite frequency (and wavelength) in the spectrum. Recall that only (luminous/non-luminous) hydrogen gas produce (bright line/continuous) emission spectra. Here we (find/do not find) an acceptable explanation of emission of bright line spectra by hydrogen.	luminous bright line find
31. When an electron moves in circular orbit it has angular momentum. This is a classical concept. Bohr postulated that the allowable orbits of the electron are those in which the angular momenta are some integral multiples of $\frac{h}{2\pi}$. This means that like energy angular momentum is also quantised. For an electron of mass m moving with a velocity v in an orbit of radius r, the angular momentum = ——	mvr

According to Bohr,

in the 1st allowable orbit of radius r_1, $mvr_1 = 1 \cdot \frac{h}{2\pi}$

in ... 2nd ... ... r_2, $mvr_2 = 2 \cdot \frac{h}{2\pi}$

in ... 3rd ... ... r_3, $mvr_3 = 3 \cdot \frac{h}{2\pi}$ and

so on.

STATEMENTS	CORRECT RESPONSE
Generalising, $mvr_n =$ —— (complete), where $n=1, 2, 3$ etc.	$n \cdot \frac{h}{2\pi}$
We know then that the —— circular orbits of the electron are those in which the angular momenta are restricted to certain values which are integral multiples of —— (complete).	allowable $\frac{h}{2\pi}$
32. Electron rotates in its orbit without radiating; this suggests that the electron in an atom behaves as standing wave extending throughout its orbit round the nucleus. Refer to Fig 7·2 (a). For electron wave to just fill the circumference of this allowable orbit, the orbit must contain an —— number of wavelengths.	integral
Fig. 7·2 (b) (does/does not) represent standing electron waves in an allowable orbit round the nucleus.	does not
33. Considering λ as the wavelength of the standing wave and r the radius of the allowable orbit, we can compute,	

$$2\pi r = n\lambda = n\frac{h}{p} \text{ (de Broglie's hypothesis)}$$

$$\text{or} \quad p \cdot r = n \cdot \frac{h}{2\pi}$$

$$\text{or} \quad mvr = n \cdot \frac{h}{2\pi}$$

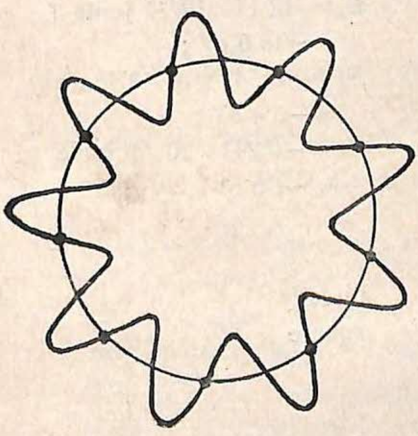


Fig. 7·2 (a)
$2\pi r = 9\lambda$
This is allowed

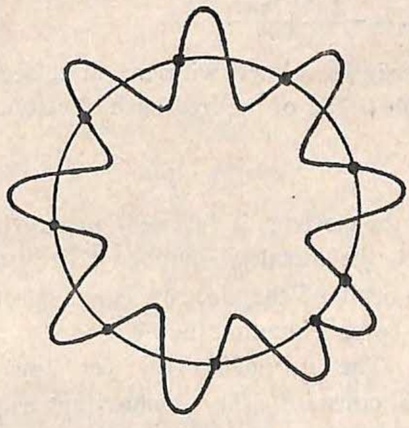


Fig. 7·2 (b)
$2\pi r = 8\frac{1}{2}\lambda$
This is not allowed

Standing wave corresponding to electron wave in an allowable orbit. $2\pi r$=integral multiple of λ.

STATEMENTS	CORRECT RESPONSE
mvr is the ——— of the electron regarded as particle. Considering electron as wave we arrive at the conclusion that angular momentum of an orbital electron is quantised. It is an ——— of $\frac{h}{2\pi}$	angular momentum integral multiple
34. Radius of the nth allowable orbit of the electron in hydrogen atom is $r_n=\frac{nh}{2\pi mv}$. Recall item 6. $mv^2=\frac{ke^2}{r_n}$ We can compute the radius of the nth orbit by combining both of these equations. The value is r_n ——.	$\frac{n^2h^2}{4\pi^2kme^2}$
35. $r_n=\frac{h^2}{4\pi^2kme^2}\cdot n^2=\text{constant}\times n^2$. Compute the value of the constant, given : $h=6{\cdot}63\times10^{-34}$ joule-sec $m=9{\cdot}1\times10^{-31}$ kg. $e=1{\cdot}6\times10^{-19}$ coulomb, and $k=9\times10^9$ newton-m^2/coulomb^2	$0{\cdot}53\times10^{-10}$ m
36. $r_n=0{\cdot}53\times10^{-10}.n^2$ It is now easy to compute the radii of various allowable orbits of the electron in a hydrogen atom. It is also possible to calculate the energy of the electron when it is in one of the allowable orbits and the atom is in one of the —— states.	stationary
Recall item 6. $E_n=-\frac{2\pi^2k^2me^4}{n^2h^2}$ Compute the energy associated with the first, second and third allowable orbits of the hydrogen electron.	$E_1=-2{\cdot}17\times10^{-18}$ joule $=-13{\cdot}6$ eV ; $E_2=-0{\cdot}543\times10^{-18}$ joule $=-3{\cdot}4$ eV ; $E_3=-0{\cdot}241\times10^{-18}$ joule $=-1{\cdot}5$ eV
37. Orbital energy of the electron is inversely proportional to n^2. n is called the quantum number. The radius of the allowable orbit of the electron is —— proportional to the —— of the quantum number n.	directly square
Recall item 36. The orbital energy for any one particular orbit is constant. This means that as long as the electron remains in this orbit it (can/cannot) lose energy by radiation. This (conforms/does not conform) to classical electromagnetic theory.	cannot does not conform
38. The radius of the first allowable orbit is called the inner most orbit ; the quantum number associated with it	

STATEMENTS	CORRECT RESPONSE
is —— . The computed value of the inner most orbit is —— m. It is very close to the accepted value for the normal radius of the hydrogen atom. This success was a great triumph for Bohr's theory.	one $0{\cdot}53\times10^{-10}$
39. In the introduction to this chapter you have been told that for its acceptance Bohr's theory of atomic structure should be able to explain the occurrence of bright line spectra of glowing hydrogen. Recall item 29. $\nu=\frac{E_i-E_f}{h}$. The equation can predict the frequency of the bright line emitted when electron from the second allowable orbit jumps to the first allowable orbit. Compute the frequency of the radiation emitted when $E_f=-2{\cdot}17\times10^{-18}$ joule and $E_i=-0{\cdot}543\times10^{-18}$ joule. Can you identify the line ?	$2{\cdot}47\times10^{15}$ Hz. It is the first line in the Lyman series in the ultraviolet region.
40. $\nu=\frac{E_2-E_1}{h}$; $E_n=-\frac{2\pi^2k^2me^4}{n^2h^2}$ Compute ν in terms of n. $\nu=\frac{2\pi^2k^2me^4}{h^3}\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]=R\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]$, where $R=\frac{2\pi^2k^2me^4}{h^3}$	
41. $R=\frac{2\pi^2k^2me^4}{h^3}$. Compute the value of R.	$R=3{\cdot}27\times10^{-15}$/sec
42. Recall your study on the spectral series of hydrogen. The spectral series equation is $\nu=R\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]$, where $R=3{\cdot}29\times10^{15}$/sec. The predicted value of R from Bohr's theory is —— . This remarkable agreement between these two values of R was considered yet another triumph for the theory.	$3{\cdot}27\times10^{-15}$ /sec
The equation $\nu=$ ——derived from Bohr's theory enables us to compute the frequency of the bright line spectrum of hydrogen. We can recognise this as identical with the spectral series equation.	$R\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]$
43. Spectral series equation was first proposed by Balmer. It (was/was not) deduced from any physical principle. We could, however, deduce the same equation now from	was not

STATEMENTS	CORRECT RESPONSE
the physical principle involved in (Bohr's atomic model /Rutherford's atomic model).	Bohr's atomic model
44. The three distinct spectral series in the emission spectrum of hydrogen are —— (name) in the infrared region, —— (name) in the visible region and —— (name) in the ultraviolet region of the e.m. spectrum.	Paschen Balmer ; Lyman
45. In Bohr's hydrogen atom when excited electron from the orbits whose quantum numbered 4, 5, 6 etc., returns to the orbit number ——, the emitted spectral series correspond to the Paschen series. Compute the first line in the series and verify if it agrees with the value mentioned in the last chapter.	$3; 1{\cdot}6\times10^{14}$ Hz. It agrees with the experimentally determined value (item 23, chapter VI).
46. $\nu=R\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]$ where n_1 and n_2 are the —— —— corresponding to orbit no. —— and —— .	quantum numbers n_1 ; n_2
When the excited electron in a hydrogen atom returns from the orbits numbered —— etc., to the orbit numbered ——, we expect to observe the Balmer series in the ——, region. Compute the frequency of the red line in the Balmer series.	3, 4, 5, 2 visible $4{\cdot}57\times10^{14}$ Hz
47. Refer Fig. 7.3. It is a simplistic scheme of transitions between stable Bohr orbits in the hydrogen atom. It is on record that when Bohr's theory was proposed only the Balmer and Paschen series for hydrogen were known. $\nu=R\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]$. The theory suggested that for values of n_1 different from 2 and 3 additional series should exist. The search for those series resulted in the discovery of the Lyman series (1916), the Brackett series (1927) and the Pfund series (1924). The frequencies predicted for the lines in these series agreed well with the experimental results. Predictions of Bohr's theory are (consistent/not consistent) with experimental observations. The theory was acclaimed highly as an excellent one capable of explaining the structure of an atom.	consistent
48. Refer Fig. 7.4. Read the paragraph carefully. The diagram is known as —— —— diagram. In it the horizontal lines represents the discrete energy states ; the —— lines represent the —— jump from one to the other energy state. In the ground level the energy of	energy level vertical ; quantum

STATEMENTS	CORRECT RESPONSE
the hydrogen atom is (maximum/minimum) being equal to —— eV. The energy required to remove the electron from the atom is —— eV. When the electron is removed from the hydrogen atom it becomes ionised; hence —— eV of energy is required to ionise a hydrogen atom; physicists call this ionization energy or ionization potential. This magnitude of the ionization potential has been verified experimentally.	minimum $-13{\cdot}6$ eV $13{\cdot}6$ eV $13{\cdot}6$ eV

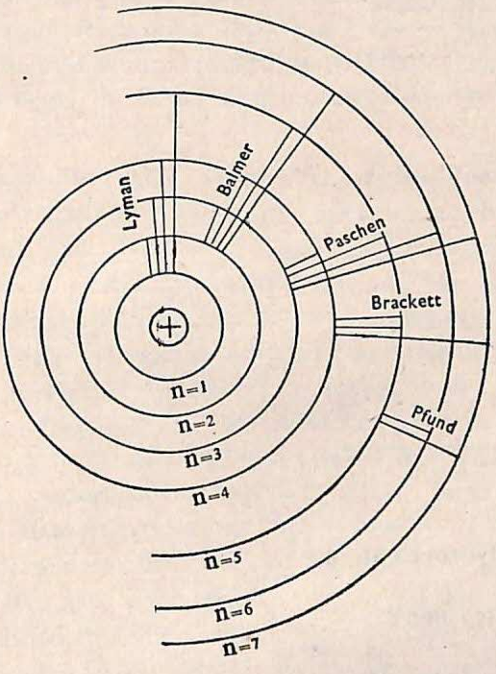


Fig. 7.3

Origin of the Series Spectra of Hydrogen atom.
Orbit Diagram (not drawn to scale).

When the electron jumps to inner most orbit from higher excited ones, hydrogen gives out Lyman series of spectral lines.

When the electron jumps to the second orbit from other higher excited ones, hydrogen gives out Balmer series of spectral lines.

When the electron jumps to the third orbit from other higher excited ones, hydrogen gives out Paschen series.

STATEMENTS	CORRECT RESPONSE
When the electron jumps to the fourth orbit from other higer excited ones, hydrogen gives out Brackett series.	
When the electron jumps to the fifth orbit from other higher excited ones, hydrogen gives out Pfund series.	

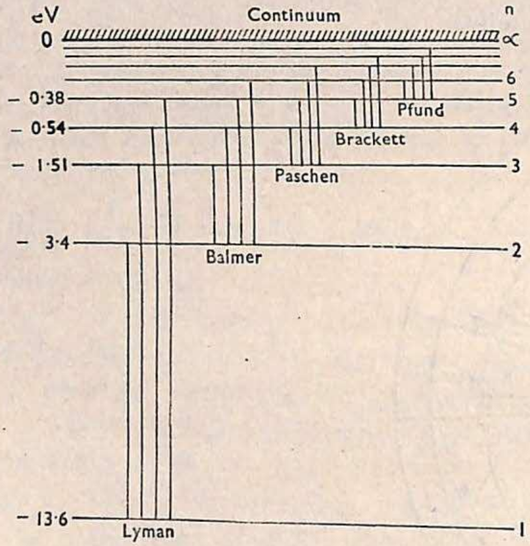


Fig. 7.4

Energy Level diagram for the Hydrogen atom

Energy of each level is indicated in eV.
Recall 1 eV$=1{\cdot}6\times10^{-19}$ J
Recall $E_1=-2{\cdot}17\times10^{-18}$ J $=-13{\cdot}6$ eV

The energy scale has been chosen in such a way that the electron has zero energy when it is completely removed from the nucleus and made free.

In the diagram, which is not drawn to scale, discrete energy states are represented by horizontal lines and various possible transitions of the atom from one to the other states, giving rise to emission of spectral lines, by vertical lines. The lowest energy level ($n=1$) corresponds to the normal unexcited state, called the ground state of the atom.

STATEMENTS	CORRECT RESPONSE
The amount of energy that must be given to an electron to cause it to jump to a higher level is much greater than the thermal energy (kT) at room temperature ; it follows, therefore, that in an atom the electrons normally occupy the lowest energy level ; and we say that the atom is in the ground state.	
49. Recall item 30. The states which corresponds to quantum no. greater than unity are called —— states. A transition from the ground state to an —— state can occur only when an atom (emits/absorbs) an amount of energy equal to the excitation energy for the excited state.	excited excited absorbs
50. We have seen that Bohr's theory can successfully explain emission of bright line spectrum of luminous hydrogen gas. We have also examined that the theory can give a satisfactory explanation of the fact that emission occurs only when the gas is luminous. Frank and Hertz performed an interesting experiment in 1914. They allowed slow electrons to collide with mercury atoms. It was observed that electrons could not transfer energy to the mercury atoms unless their energy was 4·9 eV. According to Bohr, the mercury atom has an excited state 4·9 eV above the —— state. If the state is an allowed one the energy of the excited atom should be emitted as a light quantum whose frequency could be predicted by Bohr's frequency condition. Compute the expected frequency and wavelength of the emitted radiation.	ground $1{\cdot}182\times10^{15}$ Hz 2537 Å
51. This line of wavelength 2537 Å lies in the (visible / infrared / ultraviolet) region of the electromagnetic spectrum. Frank and Hertz observed a line of wavelength 2535 Å, in the spectrum of mercury. The experimental result can be interpreted (in accordance/not in accordance) with the Bohr's theory. We explain the above phenomenon as follows : by electron impact, a —— of energy of 4·9 eV is transferred to the mercury atom and when the excited electron jumps back to the —— state, the excitation energy is emitted as a —— of frequency and wavelength as predicted from the theory.	ultraviolet in accordance quantum ground photon

STATEMENTS	CORRECT RESPONSE
NOTE :	
1. Compute the frequency of the first line in Pfund series. It (lies/does not lie) in the infrared region of the e.m. spectrum.	$4{\cdot}02 \times 10^{18}$ Hz lies
2. Which of the following statements are not true ? (i) Spectral series equation of Balmer was not derived from any physical principle. (ii) Classical electromagnetic theory cannot explain the existence of the stationary state of the atom. (iii) In Bohr's atomic theory laws of classical mechanics were pressumed to be valid for an atomic system in a stationary state but not during a transition from one such state to another. (iv) Balmer series in the hydrogen spectra cannot be explained from the point of view of Bohr's theory. (v) Frank and Hertz experimentally demonstrated that Bohr's theory could successfully explain photon absorption resulting in excitation of mercury atom. (vi) Bohr's theory is a hybrid one containing some classical ideas and some quantum idea. (vii) Rutherford's atomic model can successfully explain emission of spectral lines of hydrogen but fails to explain alpha-particle scattering by thin gold foil. (viii) The total energy of the electron in allowable orbits decreases as the radius of the orbit decreases. (ix) The radius of the allowable orbit is directly proportional to the square of the quantum no. of the orbit. (x) Angular momentum quantisation is consistent with classical concept.	(iv) ; (vii) ; (x)
3. Planck's constant has the dimension of angular momentum. Does this necessarily suggest that angular momentum is a quantised quantity ?	Although the angular momentum quantisation follows the logic of energy quantisation, role of h because of its magnitude and unit, is very important in any quantisation effect.

STATEMENTS	CORRECT RESPONSE
4. For quantum effects to be every day phenomena in our lives, what should be the minimum order of magnitude of h?	The reader advised to discuss the problem with his physics teacher. Also refer to note 13, Chapter III.
5. We summerise. Bohr applied the quantum theory of radiation, as developed by Planck and Einstein, to the Rutherford's solar system atomic model. His theory is based on the following postulates :	
(i) An atomic system possesses a number of states called stationary states in which orbital electrons, though they revolved round the positive nucleus, (do/do not) radiate electromagnetic radiation.	do not
The orbits in which electrons behave this way are the only allowable ones. This view (is/is not) consistent with the classical ideas.	is not
(ii) Any emission or absorption of radiation will correspond to a transition between two stationary states. The radiation emitted or absorbed in a transition is homogenous and its frequency ν is given by the relation : $h\nu = E_1 - E_2$	
where h is —— constant and E_1 and E_2 are the —— of the system in the two —— states.	Planck's energies ; stationary
(iii) The dynamical equilibrium of the system in the stationary states (is/is not) governed by the ordinary law of mechanics, but these laws (do/do not) hold for the transition from one state to other.	is do not
(iv) The different possible stationary states of a system consisting of an electron rotating round a positive nucleus are those for which the allowable orbits are circles determined by the relation :	
$p =$ —— (complete),	$p = n.\frac{h}{2\pi}$
where, $p =$ ——,	angular momentum of the electron
$h =$ ——,	Planck's constant
and $n =$ ——.	quantum number.

VIII

Introduction to Quantum Mechanics and Schrodinger Equation

Recall your studies on previous Chapters. From Planck's theory (Ch. I) we know that absorption and emission of radiation take place in terms of integral number of energy quanta. In Ch. II we learn that propagation of radiation through space is itself quantised into concentrated bundles called Photons. According to Einstein's theory of photoelectric emission radiant energy is shot out in discrete amounts called photons which travel through space with the speed of light. Energy of a monocromatic wave of frequency ν can assume only those values which are integral multiples of energy $h\nu$; that is $E_n = nh\nu$, where n is an integer referring to the number of photons. Thus the energy of a single photon associated with light of frequency ν is

$$E = h\nu \qquad \ldots \qquad \ldots \qquad (1)$$

Discovery of 'Compton effect' (Ch. III) provided the strongest evidence in support of the photon nature of radiation. Photon, therefore, became the most interesting example of a quantum mechanical object. Recall your ideas about matter-wave. Prince Louis de Broglie (1924), working from the postulate of quantum theory and relativistic definition of photon energy, proposed that matter must also possess wave-like properties. Possible existence of wave-matter duality in nature was suggested by him for the first time. He showed that a particle of mass m moving with velocity v is associated with waves of length given by :

$$\lambda = \frac{h}{mv} = \frac{h}{p}$$

Conversely, radiation of wavelength λ will be equivalent to a classical particle of mass $h/\lambda c$.

Further, forces known in electrodynamics, from the days of Newton, appeared inadequate for the explanation of remarkable stability of atoms and molecules (Ch. VII), which is necessary in order that materials may have their known physical and chemical properties. Introduction of new hypothetical forces at that stage could not save the situation at all, since there existed general principles of classical mechanics, holding for all kind of forces, which would lead to result in direct disagreement with observation. We had there a very striking and general example of the breakdown of classical

mechanics —— not merely an inaccuracy in its laws of motion, but an inadequacy of its concepts to supply us with a description of atomic events.

A profound change, therefore, has taken place during the present century in the opinions physicists had held on the mathematical foundation of their subject. Previously they had supposed that the principles of Newtonian mechanics would provide the basis for the description of the whole of physical phenomena. With the recognition that there was no logical reason why Newtonian and other classical principles should be valid outside the domains in which they have been experimentally verified, came the realization that departures from these principles were indeed necessary. Such departures found their expression through the introduction of new mathematical formalisms.

In 1926, Erwin Schrodinger proposed that the de Broglie wavelength be substituted in the classical wave equation, and from that beginning he derived a wave equation, now called the Schrodinger wave equation, which is the basic equation of quantum mechanics. Schrodinger equation to quantum mechanics is what Newton's equation of force to classical mechanics. Like the Newton's equation it was obtained by postulates designed to ensure its agreement with a few key phenomena ; later on it was found to be capable of explaining a very large number of others. Its field of application, called quantum mechanics as stated above, is the mechanics of microscopic systems —— atoms, molecules, crystals of solids, *nuclei* and elementary particles. For this reason, the physical phenomena to which Schrodinger's equation pertains are less familiar to you than the macroscopic phenomena that fall within the field of classical mechanics.

In this chapter the approaches which led to the formulation of Schrodinger equation will be presented step by step, pointing out the basic postulates on which the equation is based.

STATEMENTS	CORRECT RESPONSE
1. Recall de Broglie's equation : ——, where m is the mass of a particle moving with velocity v and λ is the wavelength of the associated matter-wave, h being the Planck's constant.	$mv=h/\lambda$
2. According to de Broglie a wave is (associated/not associated) with a particle because many experiments show that in certain circumstances a particle moves as if it (were/were not) governed by propagation of an associated wave.	associated were
3. In the deduction of Schrodinger equation, the first postulate is that it (must be/need not be) consistent with de Broglie's equation.	must be
4. Schrodinger's equation can be visualised as a generalisation of de Broglie's relation : $mv=?$	h/λ

STATEMENTS	CORRECT RESPONSE
5. The second postulate is related to the first. It is that the function describing the mathematical form of the wave, associated with a particle whose de Broglie wavelength is λ, must be sinusoidal, say a sine with this wavelength. The justification is that a sinusoidal is the (simplest/most complex) oscillating function for which a unique constant wavelength can be defined.	simplest
6. Recall your ideas about pendulum vibration. Refer to Fig. 8.1. It is a simple record of vibratory motion. This record, usually on paper, is called an oscillogram (from the Latin 'oscillum' for 'swing' and the Greek 'gramma' for record). The curve seen is a sinusoidal. It (can/cannot) be represented by a sine function.	can
7. Examine the curve closely. The wavelength defined as the distance between two successive points in the wave which are in the same state of vibration, (is/is not) constant throughout.	is
8. The function describing such sinusoidal is called wavefunction in quantum mechanics and is symbolised by ψ. Thus for a particle moving along the x-axis with de Broglie wavelength λ, the wavefunction can be taken to be :	

$$\psi = \sin \frac{(2\pi x)}{\lambda} \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

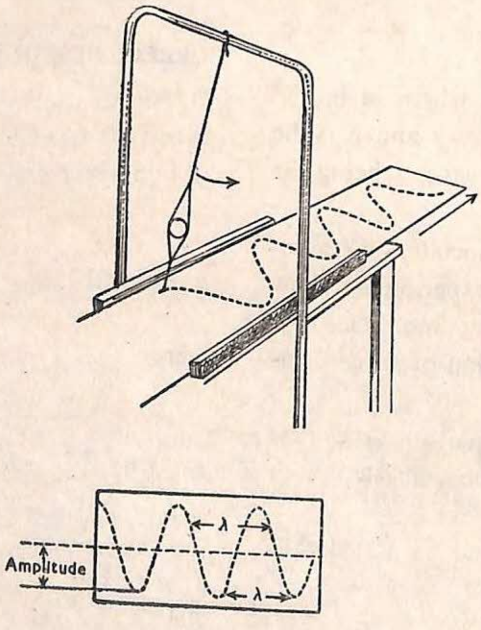


Fig. 8.1

STATEMENTS	CORRECT RESPONSE
9. $\psi = \sin \frac{(2\pi x)}{\lambda}$ represents a —— for a —— moving along the —— axis with —— wavelength λ.	wavefunction ; particle x ; de Broglie
10. Equation (2) is meaningful only for the case of a particle of constant speed v at all positions x for which, equation (1) says, λ is a constant. Write de Broglie's equation for a particle of mass m moving with velocity v : ——. If v is constant then λ (is also/need not be) a constant.	$mv = h/\lambda$ is also
11. To speak of wavelength that varies with position significantly (is/is not) consistent because such a concept (is/is not) well defined.	is not is not
12. Draw a careful sketch of an oscillating function in which the oscillation bunch closer and closer together with increasing x. Now try to decide, for a particular x, what is the wavelength. What do you conclude ?	idea of wavelength is not consistent with this type of oscillation
13. Recall item 5. In the deduction of Schrodinger's equation the second postulate is that the equation (must/need not) be consistent with eq. (2). In other words, Schrodinger equation should have eq. (2) as a solution in case of a particle of constant speed.	must
14. The third postulate is universal in nature. It assumes that Schrodinger's equation be consistent with the law of conservation of energy : $K+V=E$ ... ...(3) where K is the kinetic energy, V the potential energy and E the total energy of a particle.	
15. Eq. (3) : $K+V=E$; from the elementary definition of kinetic energy you know that $K=\frac{1}{2}mV^2$. Therefore, $\frac{1}{2}mV^2=(E-V)$. Using de Broglie's expression we obtain $\frac{1}{\lambda^2}=$—— ?	$\frac{2m}{h^2}(E-V)$
16. Eq. (2) : $\psi = \sin\left(\frac{2\pi x}{\lambda}\right)$ Differentiate ψ with respect to x. You obtain $\frac{d\psi}{dx}=\frac{2\pi}{\lambda}\cos\left(\frac{2\pi x}{\lambda}\right)$ Differentiate $\frac{d\psi}{dx}$ again with respect to x. You obtain $\frac{d^2\psi}{dx^2}=$—— ?	$-\frac{4\pi^2}{\lambda^2}\psi$

STATEMENTS	CORRECT RESPONSE
17. Recall the final expression in items 15 and 16 above. $\frac{1}{\lambda^2}=\frac{2m}{h^2}(E-V)$ and $\frac{d^2\psi}{dx^2}=-\frac{4\pi^2}{\lambda^2}\psi$ Combining both these expressions by eleminating λ, you would obtain $\frac{d^2\psi}{dx^2}=\frac{2m}{\hbar^2}(V-E)\psi$ ... ...(4) where $\hbar=h/2\pi$	
18. Rewrite eq. (4) : .... This is known as Schrödinger's one-dimensional time independent wave equation for a bound particle (whose binding force is related to potential energy V). It has been given this name because it is a differential equation of the second order in the coordinates of the system —— somewhat similar to the wave equation of classical mechanics. Utility of this equation lies in the fact that its solution enables one to calculate energy levels (called eigenvalues) of the energy E.	$\frac{d^2\psi}{dx^2}=\frac{2m}{\hbar^2}(V-E)\psi$
19. If the particle is free, $V=0$; Schrödinger equation then take the form : —— .	$\frac{d^2\psi}{dx^2}+\frac{2m}{\hbar^2}E\psi=0$
20. Recall Newton's equation of force : $\frac{d^2x}{dt^2}=\frac{F}{m}$, where F represents the force acting on a particle of mass m. Compare its form with that of Schrödinger : $\frac{d^2\psi}{dx^2}=\frac{2m}{\hbar^2}(V-E)\psi$ You are advised to note the similarity in the form of these two equations. This will help in optimising learning.	

It is beyond the scope of this book to examine Schrödinger equation and its corollaries in detail. The most advanced formulation of the equation based on the operator concept of quantum theory need not be discussed here. The new version does not invalidate the fundamental equation ; it only broadens its approach to solve complicated problems.

IX

Radioactivity

Uranium is the heaviest element which occurs in nature. Because of this the metal has been at the centre of scientific investigations for a long time. As early as in 1867 N. de. St. Victor of France reported that when a sheet of paper impregnated with uranium nitrate was exposed to light it was able to affect a photographic plate in the drak so as to cause exceptionally rapid reduction of the silver salt in the plate. However, the element and its available compounds came under closer scrutiny after the discovery of the X-rays by Wilhelm Konard Roentgen. Henry Bacquerel in 1896 showed that uranium salt emitted rays even without being exposed to sunlight, and that these persisted for a long time. In that manner was discovered the remarkable phenomenon rays to which Marie Curie, in 1898, gave the name 'Radioactivity'.

Bacquerel's discovery was soon followed by the identification of other radioactive elements, namely, thorium, polonium, radium and actinium, in which the Polish born Marie Curie and her French husband Pierre Curie played an important part. Today a large number of radioactive species are known —— some occur naturally, while others are produced by various artificial means known as transmutation processes.

At the beginning of this century, Rutherford in England was studying the effect of increasing thickness of aluminium sheets in reducing the ionising power of radioactive radiations from active materials. From his investigations he concluded that the radiations emitted by any uranium compound were of two different types ; the first, which Rutherford called alpha rays, were unable to penetrate more than about 0·002 cm of aluminium ; the second, called beta (β) rays, required a much thicker sheet of aluminium for complete absorption. The penetrating power of beta rays was observed to be very roughly a hundred times that of alpha (α) rays. A third type of radiation, which had considerable penetrating power and produced marked effect on photographic plates, was discoverd by P. Villard in France in 1900. These radiations are now called gamma (γ) rays.

Today it is well known that Rutherford's α-rays have particle nature. They are streams of energetic helium nuclei, and each of them carries two units of positive charges. The β-rays are nothing but beams of electrons. The γ-rays are highly energetic electromagnetic radiation having frequencies of 10^{20} Hz or more.

Experiments show that atoms of a radioactive substance continually disintegrate into other atoms. Some elements of high atomic weight (those above lead in the periodic table) are unstable because their nuclei are too big to be stable ; nuclei of these

elements break up giving out radiation which consist of α and β and γ-rays. These emissions are known as radioactive emanations.

Most of the naturally occurring radioactive elements radiate either alpha or beta particles. Although in a few exceptional cases both are emitted. In many cases gamma-rays accompany alpha or beta emission. The constitutional nature of each of these rays is the same, irrespective of their origin ; the α-particles are always doubly charged helium nucleus, beta particles are electrons and the γ rays are electro-magnetic waves. However, the specific properties of these radiations, such as the velocities of the α and β particles, their penetrabilities and power of ionising gases, and the wavelength of the γ-rays, vary with the particular radioactive element from which they originate.

STATEMENTS	CORRECT RESPONSE
1. Atoms whose atomic numbers are same but atomic weight differ are known as isotopes. Isotopes of an element (have/do not have) equal number of protons but (same/different) number of neutrons in their nuclei.	have different
2. The atom is electrically neutral. There should, therefore, be an equal number of protons and electrons in an atom. This suggests that the atoms of the isotopes of an element (have/do not have) identical electronic structure. Chemical processes involve (only orbital electrons/nucleus/some electrons and protons). It is expected that the isotopes of the same element (can/cannot) normally be separated by chemical means.	have only orbital electrons cannot
3. The protons of the nucleus account for all the positive charges in the atom. The electrons in the orbits (or shells) account for all the —— charges in the atom. Except for the hydrogen atom, protons (do/do not) account for the entire mass of the atom.	negative do not
4. Protons and electrons are called the subatomic particles. We know that the mass of the proton is about —— times the mass of the electron. Combined mass of the protons and electrons in an atom is less than its actual mass. To account for that difference the existence of a neutral particle having mass nearly equal to that of a proton and residing within the nucleus was predicted. Chadwick in 1932 first experimentally demonstrated the existence of such particles within the nuclei of different atoms. These particles had earlier been named neutrons. The neutron carries (no/one unit) charge and has mass (much greater than/less than/nearly equal to) that of a proton.	2000 no nearly equal to

STATEMENTS	CORRECT RESPONSE
5. Protons and neutrons together practically account for the entire mass of any atom. The word nucleon is often used to describe either of these subatomic particles. The total no. of nucleons in an atom is responsible for its (charge/mass) ; no. of protons, on the other hand, accounts for all its positive (mass/charge).	mass charge
6. In isotopes there are (equal/unequal) number of protons and an (equal/unequal) number of neutrons. We recall that the number of protons in the atom is —— for all isotopes of the same element. The total no. of nucleons, however, is different for different isotopes. The atomic number of oxygen is 8. Any isotope of oxygen has 8 (protons/neutrons) in its nucleus.	equal unequal same protons
7. No. of protons in an atom is called its —— number ; no. of nucleons in an atom is called its —— number. Isotopes are atoms whose —— —— are same but —— —— are different.	atomic mass atomic numbers ; mass numbers
8. Mass spectrometer is an instrument that enables us to distinguish between —— of the same element.	isotopes
9. Mass spectrometric study over the years have resulted in identifying about 284 stable isotopes in nature. These isotopes are distributed among 83 elements. Twenty of these (about one fourth of all) are single species ; all others have two or more isotopes. Hydrogen has two isotopes. Carbon and Nitrogen also have two isotopes each. Tin has the greatest number of isotopes, ten in number. Xenon has nine isotopes. Cadmium and tellurium have eight isotopes each. Several other elements have seven isotopes. It is known that there are three kinds of oxygen atoms distinguished by the fact that they have different masses. These (are/are not) isotopes of oxygen.	are
10. When inside the nucleus, the protons and neutrons are referred to as nucleons. The number of nucleons in an isotope indicates its mass number. Neon has an isotope of mass number 22. The atomic number of neon is 10. The number of neutrons in the nucleus of this particular isotope of neon is——.	twelve (12)

STATEMENTS	CORRECT RESPONSE
11. We use Z to represent the atomic number of an element and A to represent the mass number of its isotopes ; N is used to represent the number of neurons in the nucleus of an isotope. N=—— in terms of Z and A.	$A-Z$
12. The atomic number of silicon is 14. One of its isotopes has mass number 30. For this particular isotope of silicon, Z=——, A=—— and N=——.	14 ; 30 ; 16
13. In recent years the term 'nuclide' has been widely accepted to represent a particular species of an element, characterised by the mass no. A and atomic no. Z of its nucleus. An isotope is one of a group of two or more nuclides having the same atomic number. Scientists have developed a shorthand for the nuclides similar to that used by chemists to represent chemicals. $_{10}Ne^{22}$ represents neon nuclide whose mass no. is 22 and atomic no. 10. $_{10}Ne^{20}$ represents the other —— of neon whose mass no. is —— and atomic no. ——.	nuclide 20 ; 10
14. Nuclides which have not been observed to have undergone any change in their nuclear structures and contents spontaneously, are said to be stable. Do the atoms of stable nuclides emit radioactive radiations ? Yes/No. Explain.	No *Radioactive radiations are emitted only when there is nuclear disintegrations, which occur in unstable nuclides.

Energy Involved in Radioactive Disintegration

Let us review the properties of the different radioactive emanations. The α-rays have very weak penetrating power ; even a few sheets of paper can absorb them completely. However, they produce marked ionization of the medium through which they pass. β-rays are much more penetrating than α-rays ; some millimeters of aluminium are required to absorb them. Their ionising power, on the other hand, is appreciably less. Gamma-rays are highly penetrating ; several centimeters of lead may sometime fail to cut them off completely ; however, they produce relatively little ionization per unit distance of their path through air. A common characteristic of all of these radiations is that they affect photographic plate in the dark. We may recall that the initial discovery of radioactivity by Bacquerel was from the action of these rays on photographic plates. The different electrical properties of these radiations can be summerised by subjecting them to a magnetic field as shown in Fig. 9.1.

Read the detail of the diagram carefully.

STATEMENTS	CORRECT RESPONSE
15. In the diagram α-particles are deflected to the (right/left) ; β-particles are deflected to the (right/left) γ-rays are not deflected by the magnetic field. We conclude that the nature of the charge carried by the α-particle is (same as/opposite to) that carried by the β-particle. Deflection of the β-particles is (more/less) than that of the α-particles. This is because β-particles are (much lighter/heavier/just lighter) than α-particles.	right ; left opposite to more much lighter
16. α-particles are doubly charged helium nuclei ; they are symbolised by $_2He^4$. Each of them consists of two protons and two neutrons. Mass of the proton is $1{\cdot}672 \times 10^{-27}$ kg and that of neutron is $1{\cdot}675 \times 10^{-27}$ kg. Compute the mass of the α-particle in nearest whole number.	7×10^{-27} kg
It is known that the speed of an α-particle in vacuum is about 10^7 m/s. Use this additional information to calculate (approximately) its kinetic energy.	2×10^6 eV

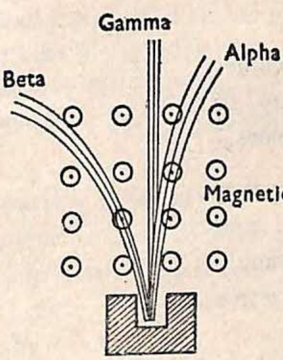


Fig. 9.1

Marie Curie's representation of alpha, beta and gamma rays in a magnetic field.

The radioactive material is placed in a narrow but deep cavity in a block of lead. A strong magnetic field is applid in a direction perpendicular to and out of the plane of the paper. The alpha particles being positively charged and relatively heavy are slightly deflected to the right.

The beta-particles being negatively charged and light are deviated much more than alpha-particles but to the left of the diagram. The gamma-rays which carry no electric charge are not deflected at all.

The above scheme is generally known as Marie Curie's representation since she included it in her doctorate thesis published in 1903.

STATEMENTS	CORRECT RESPONSE
17. β-particles are streams of electrons and move with speed comparable to the speed of light. Rest mass of an electron is $9{\cdot}1\times10^{-31}$ kg. Compute the relativistic mass of a β-particle moving at about 95% of the speed of light. Then estimate the KE of a β-particle in eV.	

$$m=\frac{m_0}{\sqrt{1-v^2/c^2}}=\frac{9{\cdot}1\times10^{-31}}{\sqrt{1-(0{\cdot}95)^2}}\simeq\frac{9{\cdot}1\times10^{-31}}{0{\cdot}3}$$

$$\approx 3\times10^{-30}\text{ kg}$$

$$KE=\tfrac{1}{2}mv^2=\tfrac{1}{2}\times3\times10^{-30}\times({\cdot}95\times3\times10^{+8})^2\text{ joule}$$

$$\simeq 1{\cdot}2\times10^{-13}\text{ joule}\simeq10^6\text{ eV}$$

18. Gamma photons are associated with frequencies of 10^{20} and higher. Estimate the energy in eV of a γ-photon with frequency $\nu=10^{20}$ c.p.s.	4×10^5 eV
19. Estimated KE of α-particle $\simeq 10^6$ eV $=1$ MeV. (Million electron volt). Estimated KE of β-particle $\simeq 10^6$ eV $=1$ MeV. Estimated KE of γ-photon $\simeq 10^5$ eV. Note : These are very rough estimates. Actual values vary and may range over several orders of magnitude for different radioactive substances.	
20. Refer the table 2. It gives a rough estimate of energy (per molecule) involved in some typical chemical and physical reactions. Which of these processes supply enough energy to produce the energies of radioactive emissions ?	none
21. The interactions responsible for the emanations from radioactive substances involve energies of about (1/100 /1000000) eV. Most chemical reactions involve energies which are not greater than (10/100/10^6) eV.	1000000 eV 100 eV
22. Chemical combustion of carbon or petrol involves energies of the order of (eV/MeV). Radioactive emissions involve energies of the order of (eV/MeV).	eV MeV
23. We are now in a position to realise that chemical reactions which involve only outer shell electrons of the atoms, involve energies less than 100 eV. It is (likely/ unlikely) that the emission of α-particles, β-particles and γ-photons result from chemical reactions.	unlikely

STATEMENTS	CORRECT RESPONSE
24. Using Coulomb's equation for electrostatic potential (refer to item 6, Ch. VII), $W=\frac{-k.e^2}{2.R}$, where R is the radius of the nucleus ($\sim 10^{-15}$m), estimate the energy involved between two protons in the nucleus. Given, $e=1{\cdot}6\times10^{-19}$ coulomb, and $k=10^{10}$ N-m^2/coulomb^2.	$W=10^6$ eV
25. Radioactive emissions are likely to originate in the (electronic shells/nucleus) of an atom.	nucleus
26. We may conclude that an understanding of the radioactive phenomenon requires a knowledge of [(i) the particles which emanate from the atomic nucleus/(ii) the way electrons are distributed in different shells of the atom].	(i)
27. Radioactive emanations must be associated with changes which take place [(*i*) in the nucleus/(*ii*) in the electron shell structure].	(i)
28. The nature of radioactive emission is such that we expect changes to take place in [(i) the mass only/(ii) the charge only/(iii) neither the mass nor the charge/(iv) either the mass or charge or both in the nucleus of the radioactive nuclide].	(iv)
29. An alpha particle consists of 2 neutrons and 2 protons. When a radioactive nuclide (also called radio-nuclide) emits an alpha particle, its atomic number (increases/decreases) by —— and its mass number (increases/decreases) by —— .	decreases ; 2 decreases ; 4
30. The mass of a β-particle is negligibly small compared to that of a proton or neutron. When the nucleus of a radio-nuclide emits a β-particle its atomic number (increases by 1/decreases by 1/ remains the same) and its mass number (increases by 1/decreases by 1/remains the same).	increases by 1 remains the same
31. A γ-photon has rest mass zero and it carries no charge. The emission of a γ-photon by the necleus of a radio-nuclide (changes/does not change) its atomic number. It leaves the mass number of the nuclide (changed/unchanged).	does not change unchanged
32. The atomic number of uranium is 92. One of its isotopes has the mass no. 238 and is radioactive. This	

STATEMENTS	CORRECT RESPONSE
radio-nuclide can be represented by the symbol ——. When it emits an alpha-particle, the isotope which remains has an atomic no. —— and a mass no. ——.	$_{92}U^{238}$; 90 ; 234
33. The new element formed, as referred to in item 32, is a nuclide (isotope) of thorium ($Z=90$) with a mass no. $A=$——. This nuclide then emits a beta particle. The atom which results has $Z=$—— and $A=$——.	234 ; 91 ; 234

Nuclear Equations

STATEMENTS	CORRECT RESPONSE
34. This type of change involving the nuclear structure and content is called radioactive decay. Refer to item 13. Any nuclide can be represented by a symbol which is reminiscent of a chemical symbol. Analogically like chemical equations describing chemical changes, physicists have developed nuclear equations to describe nuclear changes. Symbols use to describe nuclear changes (must/need not) refer to the atomic numbers and the mass numbers of the nuclei involved. Reader should note that radioactivity is a nuclear phenomenon and involves only the nuclei of atoms.	must
35. Write a nuclear equation to represent the radioactive decay mentioned in item 32 involving uranium.	$_{92}U^{238} \rightarrow {}_{90}Th^{234} + {}_{2}He^{4}$
36. Examine the above equation carefully. The number of nucleons on the r.h.s of the parent nucleus is (equal/unequal) to the total no., of nucleons distributed among the product nuclei. The atomic number representing the no., of —— in the former should be (equal/unequal) to the total no., of protons the product nuclei.	equal ; protons ; equal
37. Radium is the element discovered by (Marie Curie/Rutherford/Bacquerel) ; it is highly radioactive ; one of its isotopes is formed by α-decay of thorium nuclide of mass number 234. Can you write down the nuclear equation to describe the process ?	Marie Curie ; $_{90}Th^{234} \rightarrow {}_{88}Ra^{230} + {}_{2}He^{4}$
38. In a nuclear equation the sum of the atomic (Z) and mass (A) numbers on both sides should be (same/different).	same
39. The highly precious isotope of natural uranium is $_{92}U^{235}$ (used to be called actino-uranium). When it decays by emitting an α-particle it becomes ——. Write down the nuclear equation.	an isotope of thorium ; $_{92}U^{235} \rightarrow {}_{90}Th^{231} + {}_{2}He^{4}$

STATEMENTS	CORRECT RESPONSE
40. When the nucleus of a radioactive isotope (or nuclide) emits an alpha-particle, the value of Z (1) increases by 2, (2) decreases by 2, (3) increases by 1, (4) decrerses by 1, (5) increases by 4, (6) decreases by 4, (7) remains unchanged, while the value of A [choose from (1) to (7)]	(2) ; (6)
When the nucleus of a radioactive isotope (or nuclide) emits a beta particle. the value of Z [choose from (1) to (7) above] while the value of A [choose from (1) to (7) above].	(3) ; (7)
As the rest mass of a γ-photon is —— and it carries no charge, its emission from the nucleus (does/does not) effect its structure or content.	zero does not
41. As a result of physical and chemical research on the nature of the naturally occurring radioactive elements, it was suggested that each radioactive nuclide is a member one of three long chains or radioactive series, stretching through the last part of the periodic table. These series are named Uranium, Actinium and Thorium series. In the Uranium series, the mass number of each member can be expressed in the form $(4n+2)$, where n is an integer Uranium series is referred to as '$4n+2$' series. In the actinium and thorium series, the mass numbers are given by '$4n+3$' and '$4n$' respectively. Their is no natural radioactive series of nuclides whose mass numbers are represented by '$4n+1$'.	
Polonium is a radioactive element first identified by Marie Curie. Its nuclear symbol is $_{84}Po^{218}$. It is a member of (Uranium/Actinium/Thorium) series because its mass no., —— can be expressed in the form of ——.	Uranium 218 ; $4n+2$
42. The radionuclide $_{83}Bi^{215}$ belongs to —— series because its mass no., —— can be expressed in the form of ——.	Actinium 215 ; $4n+3$
43. The radio-nuclide $_{84}Po^{212}$ belongs to——series because its mass no. —— can be expressed in the form of ——.	Thorium 212 ; $4n$
44. It is interesting to note that the last element in all the three series is lead which is a stable element. The	

STATEMENTS	CORRECT RESPONSE
isotope of lead $_{82}Pb^{206}$ belongs to —— series. It (does/does not) emit radioactive rays. Another isotope of lead $_{82}Pb^{207}$ belongs to —— series. It (does/does not) emit radioactive rays. The isotope $_{82}Pb^{208}$ belongs to —— series.	Uranium does not Actinium does not Thorium
45. The element lead is not radioactive. In the periodic table elements above lead (with the exception of $_{83}Bi^{209}$) are ——. Mass numbers of these elements are greater than that of lead. This indicates that the phenomenon of radioactivity is (likely/unlikely) due to excess of nucleons in the nucleus.	radioactive likely

Nuclear Stability and Binding Energy

STATEMENTS	CORRECT RESPONSE
46. Refer Fig. 9.2. It is a plot of number of neutrons (N) against the number of protons (Z) in all known stable nuclides. By its side is drawn a hypothetical straight line (dashed) of slope 1. Points lying on this line represent nuclides containing equal no. of protons and neutrons. The experimental curve (does not agree/agrees well/agrees only partly) with this (hypothetical) curve.	agrees only partly
47. The ratio (N/Z) is nearly equal to (0·5/1/2) for nuclides of low mass number. The experimental curve (agrees/does not agree) with the hypothetical straight line at these points. In fact, of the 18 nuclides with mass numbers through 20, there are equal number of neutrons and protons in eight and a difference of only one in nine others.	1 agrees
48. Refer Fig. 9.2. When the no. of protons in the nucleus is greater than 20, the ratio (N/Z) in stable nuclides is (always greater / sometimes greater / less) than unity. Here we observe a (rapid/gradual) departure of the experimental curve from the hypothetical straight line. This suggests that with increasing mass number there are more neutrons in the nucleus than protons. Points at the end of the curve represent heaviest stable nuclides $_{82}Pb^{208}$ and $_{83}Bi^{209}$. The ratio of neutrons to protons in their respective nuclei is nearly equal to (1/1·5/2).	always greater gradual 1·5
49. We conclude that for the stability of nuclides with atomic no. more than —— (number), there should be (more/less) neutrons in the nucleus than protons.	20 more

STATEMENTS	CORRECT RESPONSE
50. Proton which is positively charged (repels/attracts) other protons in the nucleus. As a result the electrostatic (repulsive/attractive) force (grows/decreases) rapidly with increasing atomic number.	repels; repulsive ; grows
51. Refer to item 24. The total electrostatic repulsive energy in a nucleus is roughly proportional to Z^2/R, where Z is the no. of protons in the nucleus whose radius is R. The prediction on the basis of this equation (agrees well/disagrees) with the contention in item 50.	agrees well

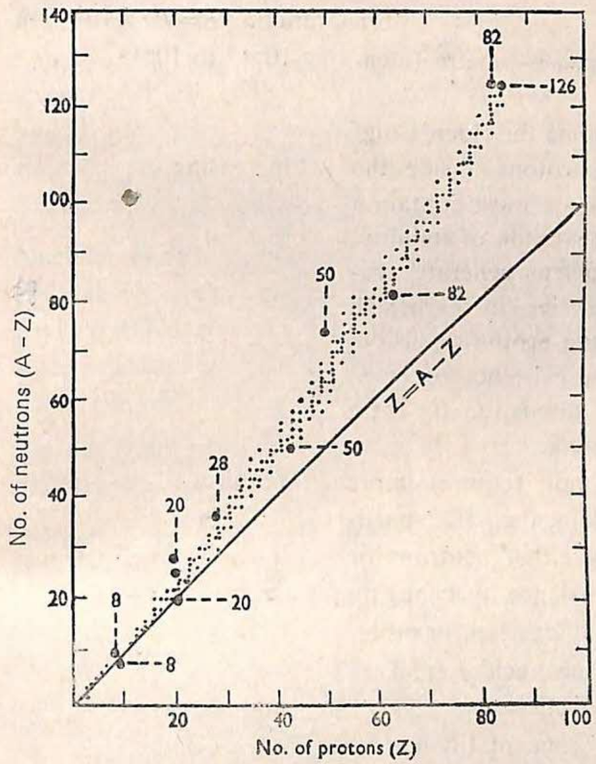


Fig. 9.2

Number of neutrons and protons in stable nuclei ; the straight line of slope 1 indicates positions of nuclei having equal number of protons and neutrons.

The straight line is a hypothetical one and is drawn only to bring out the character of the experimental curve.

STATEMENTS	CORRECT RESPONSE
52. Physicists have established a direct cube root relationship between the radius of a nucleus and its mass number : $R \propto A^{\frac{1}{3}}$. The value of the constant of proportionality has been computed as $1{\cdot}25 \times 10^{-15}$ m.	
The electrostatic repulsive energy within a nucleus is determined by the factor —— (in terms of Z and A).	$Z^2/A^{\frac{1}{3}}$
Compute the ratio of the repulsion energy of the protons in $_{83}Bi^{209}$ and $_{20}Ca^{40}$.	10 : 1
53. $R = 1{\cdot}52 \times 10^{-15}$. $A^{\frac{1}{3}}$ m ; compute the nuclear radii of carbon ($A=12$) and uranium ($A=238$) atoms.	for carbon, $R = 2{\cdot}8 \times 10^{-15}$ m ; for Uranium, $R = 7{\cdot}7 \times 10^{-15}$ m
54. All nuclear radii lie within the range —— metre (mention the order only).	10^{-15} to 10^{-14}
55. Refer to item 52. In order to overcome the (increasing/decreasing) repulsion among the protons inside the nucleus, the nuclei of heavier elements must contain a larger proportion of neutrons for the reason of stability. The additional neutrons in the nucleus generate neutron-proton, neutron-neutron attractive forces which partly compensate the growing proton-proton repulsion. The reader is advised to accept the existence of (n–n) and (n–p) interactions as true. A discussion on these forces is beyond the scope of this book.	increasing
56. Nuclear stability (requires/does not require) more neutrons in the nucleus of heavy elements. If a particular nucleus contains an excess of either neutrons or protons, it will try and redress the balance by changing the proportion by enitting particles of one type or other.	requires
Excess of protons or neutrons in the nucleus (makes/does not make) the nuclide radioactive.	makes
57. Examine Fig. 9.2 carefully. The element tin has 50 protons in its nucleus. It has ten isotopes having neutron numbers from 62 to 74. Their mass numbers lie between —— to ——.	112 ; 124
The ratio N/Z for the lightest nuclide is ——	1·24
and that for the heaviest one is ——. We call this range the stability range for the atomic number 50.	1·48
58. The stability range for the element of atomic number 50 lies between —— and ——.	1·24 ; 1·48

STATEMENTS	CORRECT RESPONSE
The most abundant isotope of an element is the (most stable/extremely unstable) one. It is (likely/unlikely) that the most abundant isotope of an element could be found near the middle of this stability range.	most stable ; likely
The mid-point of the stability range of tin has N/Z ratio as ——;	1·36
this means that the most stable tin nuclide has —— neutrons in its nucleus.	68
The corresponding nuclear symbol is ——. This is one of the two most abundant isotopes of tin.	$_{50}Sn^{118}$
59. The N/Z ratio in $_{92}U^{238}$ is about ——.	1·6
This indicates that the nucleus of this uranium isotope has (excess/less) neutrons than is required for stability. Uranium nucleus is, therefore, unstable.	excess
60. Examine Fig. 9.2. The stability range for iron (Fe) of atomic number 26 lies between —— and ——.	1·1 ; 1·2
The mid-point of this range corresponds to the neutron no.; ——. The most stable isotope of iron is ——. This agrees well with the experimental observations.	30 ; $_{26}Fe^{56}$
61. Nuclides having neutron to proton ratio lying outside the stability range for the particular atomic number are (likely/unlikely) to be unstable.	likely
They will seek stability by (emitting/absorbing) particles and radiations of one type or other.	emitting
They (are/are not) radioactive.	are

62. Accepted values for the mass of the proton, neutron and electron are as follows :

mass of the proton, $m_p = 1{\cdot}672 \times 10^{-27}$ kg
mass of the neutron, $m_n = 1{\cdot}675 \times 10^{-27}$ kg
mass of the electron, $m_e = 9{\cdot}108 \times 10^{-31}$ kg

Atomic number of an element is represented by Z and its mass no., by A. The nucleus of the atom of an element contains $(A - Z)$ neutrons. It is possible to compute the mass of the nucleus of an atom or of the atom itself, by knowing its Z and A values. But involvement of such small quantities make calculations difficult. One convenient way out was devised by scientists by defining a new mass unit called atomic mass unit (a.m.u.). It is known that the mass of an atom in grams can be obtained by dividing its mass in the atomic weight scale by the Avagadro number i.e.,

STATEMENTS	CORRECT RESPONSE
$6{\cdot}022 \times 10^{23}$. It follows, therefore, that 1 a.m.u. is equivalent to $\frac{1}{6{\cdot}22 \times 10^{23}}$ gm $= 1{\cdot}6604 \times 10^{-24}$ gm Compute the mass of the proton, neutron and electron in a.m.u. Compute the mass of the hydrogen atom in a.m.u.	1·00728 a.m.u. 1·00867 a.m.u. 0·000549 a.m.u. 1·00783 a.m.u.
63. Strong electrostatic repulsive forces exist in a nucleus due to the presence of protons there. To overcome this and give the nucleus stability scientists assumed existence of strong attractive nuclear forces tending to keep the nucleus intact. Huge amount of energy is required to keep the nucleus stable. Amount of energy required to keep the nucleons in the nucleus bound is regarded as the binding energy of the nucleus. We examine the stability of an alpha-particle which is nothihg but the nucleus of helium, ${}_2He^4$. There are two protons and two neutrons. The mass of a proton in atomic mass unit (a.m.u.) is 1·00728 ; that of a neutron is 1·00867. Hence the total mass of the constituent of an alpha particle would be —— (compute).	4·0319 a.m.u.
The actual mass of an alpha-particle determined from a large number of experiments is 4·0017 a.m.u. Mass of the helium nucleus is (more/less) than the total mass of its constituent particles by ——. This discrepency in the calculated and experimental results is known as mass defect.	less 0·0302 a.m.u.
64. Mass defect in helium nucleus is —— a.m.u. Following Einstein's mass energy equation $\triangle E =$ —— (complete), compute the energy equivalent of this mass, given 1 a.m.u. $=931{\cdot}4$ MeV.	0·0302 ; $\triangle mc^2$ $\triangle E = 0{\cdot}0302 \times 931{\cdot}4$ MeV $= 28{\cdot}1$ MeV.
65. When two neutrons and two protons are bound to form a helium nucleus there is (a decrease/an increase) in their total mass so as to release —— MeV of energy. This energy is a measure of the binding energy of an alpha particle.	a decrease 28·1
66. Binding cnergy of the helium nucleus is 28·1 MeV. To break the nucleus into its constituent particles 28·1 MeV energy is required to be supplied from outside. This is a huge amount of energy. This shows that the alpha-particle is —— —— .	extremely stable

STATEMENTS	CORRECT RESPONSE
67. Binding energy of a nucleus is a measure of its stability. We can derive a simple equation to calculate the binding energy of the nucleus in terms of Z and A. In any nucleus, there are Z no., of protons and —— no., of neutrons. Hence the mass defect in the nucleus $=Z.m_p+(A-Z)\,m_n-M_n$	$(A-Z)$
where m_p= mass of the ——	proton
m_n= mass of the ——	neutron
and M_n= experimentally observed mass of the nucleus. M_n can be easily computed from known atomic masses by subtracting the combined mass of the orbital electrons. We calculate ; Binding energy $=931{\cdot}4\,[Z.m_p+(A-Z)\,.m_n-M_n]$ MeV.	
68. Refer the table 3. It lists the atomic masses of some naturally occurring stable nuclides. The masses are based on C^{12} scale. Atomic mass of $_{10}Ne^{20}=19{\cdot}992440$ a.m.u. Binding energy in MeV $=931{\cdot}4\,[10\times1{\cdot}00728+(A-Z)\,m_n-M_n]$. Compute the binding energy of $_{10}Ne^{20}$ nucleus. M_n, the mass of the nucleus of $_{10}Ne^{20}$ = Atomic mass − mass of electron $=19{\cdot}992440-0{\cdot}00549=19{\cdot}9870$ a.m.u.	$BE=931{\cdot}4\,[10\times1{\cdot}00728+10\times1{\cdot}00867-19{\cdot}9870]$ $=160{\cdot}7$ MeV
69. Compute binding energy of $_{83}Bi^{209}$ given its atomic mass $=208{\cdot}9804$ a.m.u.	1641 MeV
70. Compute the binding energy of $_{92}U^{238}$ given its atomic mass $=238{\cdot}0486$ a.m.u.	1804 MeV
71. Compute the binding energy of $_{26}Fe^{56}$ given its atomic mass $=55{\cdot}9349$ a.m.u	492·4 MeV
72. Refer Fig. 9.3. It is a plot of binding energy per nucleon as a function of mass number of naturally occurring nuclides. Compute the binding energy per nucleon on the nuclides describe in items 67 to 71.	

For $_2He^4$, BE per nucleon $=7{\cdot}03$ MeV
... $_{10}Ne^{20}$ ... ... $=8{\cdot}04$ ...
... $_{83}Bi^{209}$ ... ... $=7{\cdot}85$ ...
... $_{92}U^{238}$ ... ... $=7{\cdot}58$ ...
... $_{26}Fe^{56}$ ... ... $=8{\cdot}79$ ...

STATEMENTS	CORRECT RESPONSE
73. Examine Fig 9.3. The curve shows a striking regularity. Binding energy per nucleon for He^4, C^{12} and O^{16} (do/do not) lie on the curve. Values of D^2 and He^3 are (low/high). Over a very considerable range of mass numbers, the binding energy per nucleon is closes to (8/7/9) MeV.	do not low 8
74. Fig. 9.3. The binding energy has a broad maximum close to 8·5 Mev per nucleon in the mass number ranging from about —— to ——. As the mass number increases further the value (increases/decreases).	40 ; 120 descreases
75. The value of binding energy per nucleon for Uranium is about —— MeV. This shows that as mass no. increases the binding energy per nucleon decreases.	7·6
76. Diminution in binding energy with (increasing/decreasing) mass no. suggests it to be the reason why heavy nuclides are radioactive.	increasing
77. Refer Fig. 9.3. The binding energy per nucleon is (highest/lowest) for nuclides of mass no. 56 i.e. $_{26}Fe^{56}$. This explain why iron is so abundant in nature.	highest
78. Six nuclides O^{16}, Mg^{24} ; Si^{28} ; Ca^{40} , Ti^{48} and Fe^{56} constitute about 80% of the earth's crust. Binding energy per nucleon for each of them is about (7/8/9) MeV. This value is accepted as the average energy associated with the attachment to or removal from a nucleus of a neutron or a proton.	8

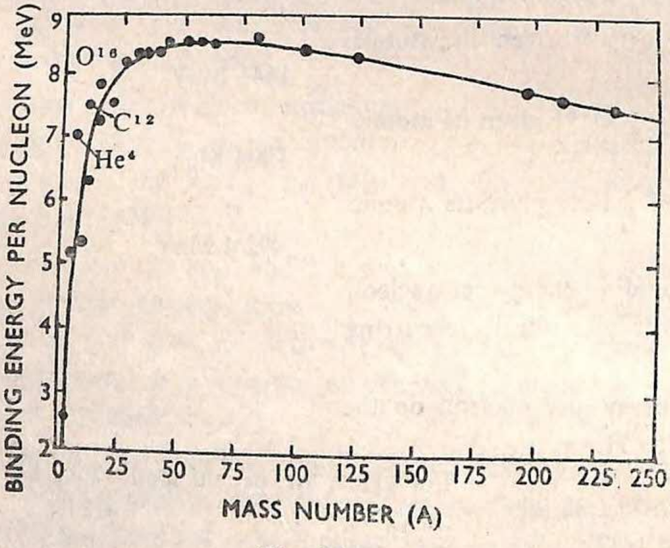


Fig. 9.3

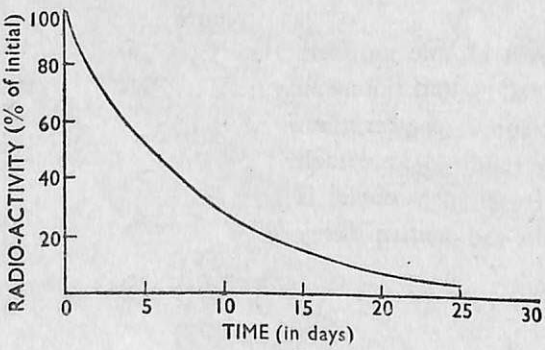
Binding energy per nucleon plotted as a function of mass number of stable nuclides

STATEMENTS	CORRECT RESPONSE
79. Radioactivity was first detected in heavy nuclei belonging to the elements lying at the extreme end of our well known periodic table. They are mostly alpha emitters. Observations have shown that this type of radioactivity is common among elements with mass number exceeding 210.	
Refer items 69 and 70. The total binding energy of $_{83}Bi^{209}$ is —— MeV ; that of $_{92}U^{238}$ is —— MeV.	1641 ; 1804
In this range of mass numbers, the mean binding energy per additional nucleon is —— MeV.	5·6
80. Mean binding energy per additional nucleon in the above radioactive range is 5·6 MeV. The energy necessary to detach two neutrons and two protons from the nucleus of one such atom to form an alpha particle is —— MeV.	$4 \times 5{\cdot}6$ MeV $=22$ MeV
81. The binding energy of an alpha-particle is about ——	28
MeV. Calculations have shown that if α-decay is to take place at an observable rate, α-particle must have about 5 MeV energy. Hence for α-particle emission to be detected, the detachment from the nucleus of two protons and two neutrons should require less than 23 MeV, approximately. In nuclei where detachment of two protons and two neutrons require less than —— MeV, α-emission (would/would not) take place.	23 ; would
82. Refer to Item 80. The energy necessary to detach two protons and two neutrons from the nuclei of heavy elements from Bi^{209} to U^{238} is (less/more) than 23 MeV.	less
We conclude that for these nuclei α-emission is (more/less) probable.	more
83. Calculations made for elements with atomic numbers somewhat less than that of bismuth show that the mean binding energy per additional nucleon is greater than 6 MeV. Consequently, the energy required to detach two protons and two neutrons from such nuclei is greater than 24 MeV. α-emission in radioactive decay of such atoms (is/is not) likely.	is not

Half-Life of Radioactive Decay

84. Nuclei which are stable (do/do not) emit α-rays, β-rays	do not
or γ-rays. Nuclei which emit radioactive radiations (disintegrate/do not disintegrate) with time.	disintegrate

STATEMENTS	CORRECT RESPONSE
85. Disintegration of radioactive nuclei into lighter nuclei has been observed to take place at a constant rate. The process is also known as radioactive decay implying that it is accompanied by a decrease in the —— of the disintegrating nucleus.	mass
86. Refer to Fig. 9.4. It is called the decay curve obtained by plotting radioactivity of Thorium *X* against time in days. At any time the amount of original radioactive substance present is the measure of activity. As activity of the element decreases with time, the ordinate is expressed as a percentage of the initial activity. At time $t=0$, the activity is taken as 100 ; the activity remaining after time t is expressed as a fraction of the initial and multiplied by hundred. Decay curves (indicate/do not indicate) the rate of disintegration of radioactive nuclides.	indicate
87. Experiment have established the fact that decay curves are characteristics of individual elements. The rate of disintegration of uranium is (different from/same as) that of radium.	different from
88. Refer to Fig. 9.4. The activity measured diminish in, what the mathematicians call, an exponential (or logarithmic) manner. This would mean that the number of atoms (or nuclei) which disintegrate in unit interval of time is proportional to the total number of atoms (or nuclei) of the species present at that time. Since disintegration takes place continuously, the number of	



Decay of Thorium *X* as observed by
Rutherford and Shoddy

Fig. 9.4

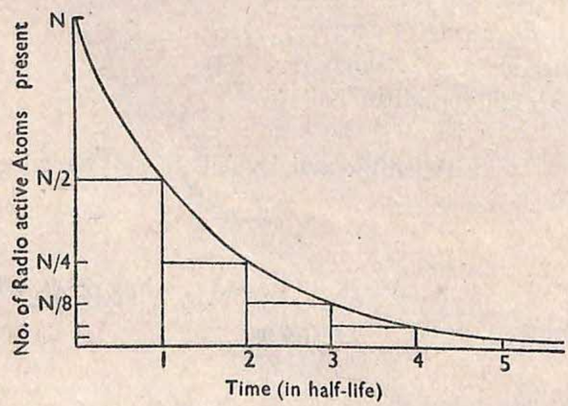
STATEMENTS	CORRECT RESPONSE
atoms (or nuclei) present also decreases continuously and so also the rate of disintegration. The shape of the decay curve is (exponential/linear) in nature.	exponential
*89. Exponential nature of the decay curve suggests that in any instant of time the rate of disintegration is (directly/inversely) proportional to the number of atoms present at that time. Using mathematical symbol we can write $-\frac{dN}{dt}=$ Rate of disintegration. The minus sign takes care of the fact that the number of atoms present is decreasing with time.	directly
$\therefore \quad -\frac{dN}{dt}\propto N$ or $-\frac{dN}{dt}=\lambda N$ where λ is the constant of proportionally which is called the disintegration constant for the particular species of atom disintegrating.	
λ is a definite and specific property of a given radio-element. Its value depends only on the nature of the species and is independent of the physical condition or state of chemical combination. Values of λ for Uranium and thorium are (same/different).	different
90. $-\frac{dN}{dt}=\lambda N$. Carrying out the process of integration. $N_t=N_o e^{-\lambda t}$, where $N_o=$ No. of atoms present initially, $N_t=$ No. of atoms remaining after the lapse of time t. This is an —— relationship.	exponential
91. $N_t=N_o e^{-\lambda t}$. Radioactivity of a particular species of atom follows an exponential decay with a rate of decay governed by the disintegration constant λ. Calculate the time taken for the radioactivity to fall to half of its initial value.	When the activity falls to half its value, $\frac{N_t}{N_o}=\frac{1}{2}$

$$\therefore \quad \tfrac{1}{2}=e^{-\lambda t_{\frac{1}{2}}} \text{ or } -\lambda\, t_{\frac{1}{2}}=\ln\tfrac{1}{2} \text{ or } \lambda t_{\frac{1}{2}}=\ln 2$$

$$\text{or } t_{\frac{1}{2}}=\frac{0{\cdot}693}{\lambda}$$

* In a radioactive atom, changes take place in the nucleus and hence it changes. In radioactivity, therefore, atoms and nuclei are generally interchangable expressions.

STATEMENTS	CORRECT RESPONSE
92. $t_{\frac{1}{2}}=\frac{0{\cdot}693}{\lambda}$. $t_{\frac{1}{2}}$ is known as 'half-life' of the particular atomic species i.e., element. It measures the time in which activity of a paticular radioelement decays to —— its initial value. This is an alternative to decay constant and was introduced to physics by Rutherford.	half
93. Use of the term 'half-life' is popular now a days; tables giving the half-lives of a large number of radionuclides are available. Half-life of $_{92}U^{238}$ is $4{\cdot}5\times10^{9}$ years. Calculate the disintegration canstant of the nuclide.	$4{\cdot}88\times10^{-18}\ \text{sec}^{-1}$
94. Half-life of $_{88}Ra^{228}$ is 6·7 years. You are given 10 gm of radium to perform an experiment which will require about 3 years 4 months to complete. The amount of radium that will be left with you at the end of the experiment is about (5/2/7) gm.	7
95. Half-life of radon gas is about 4 days. If 20 gm of radon is freshly separated then after 4 days the amount that will be left with will be —— gm.	10
96. $_{6}C^{14}$ is a carbon nuclide which is radioactive. Its half-life is about 5000 years. Calculate its decay constant in sec^{-1}. If there were 100 kg of C^{14} in the atmosphere 5000 years back, how much of it is left with now? How much of it will be there after another 5000 years.	50 ; 25
97. $_{11}Na^{24}$ is a sodium nuclide and is radioactive. It is man-made and so artificial. Its half-life is about 15 hr. If initially 100 gm of $_{11}Na^{24}$ are given to you, the	



Exponential Time Course of Radioactive Decay

Fig. 9.5

STATEMENTS	CORRECT RESPONSE
amount that will be left with after 30 hr will be (50/25/60) gm ; the amount that will be left with after 60 hr. will be (10·5/12·5/6·25) gm.	25 6·25
98. Fig. 9.5. It is called the exponential time-course of radioactive decay. The ordinate represents the radioactivity and the abscissa the time in half-life scale. The curve is —— in nature. It shows that at the end of 3rd half-life the amount of activity present is ($\frac{1}{8}$th/$\frac{1}{4}$th/$\frac{1}{16}$th) of the initial activity.	exponential $\frac{1}{8}$th

99. The activity of a radioactive sample is measured in terms of the number of disintegration occurring per second. The unit of radioactivity is 'curie', abbreviated Ci. 1 curie is defined as $3{\cdot}7\times10^{10}$ disintegration per second (d.p.s.). This is approximately equal to the activity of 1 gm of pure radium and is very high activity from the point of view of biological hazard.

Ca^{45} in an artificially prepared radionuclide. Its half life is 167 days. Compute the amount of Ca^{45} required to give one Ci of activity.

$$\lambda=\frac{0{\cdot}693}{167\times24\times60\times60}=4{\cdot}8\times10^{-8}\ \text{sec}^{-1}$$

No. of atoms present in x gm of $Ca^{45}=\dfrac{x\times6\times10^{23}}{45}$

Of these the no. disintegrating per sec.

$$=\frac{x\times6\times10^{23}}{45}\times4{\cdot}8\times10^{-8}$$

$$=x\times\frac{6\times4{\cdot}8}{45}\times10^{15}$$

$$=x\times6{\cdot}4\times10^{14}$$

1 Ci of activity $=3{\cdot}7\times10^{10}$ d.p.s.

$$\therefore\quad x=\frac{3{\cdot}7\times10^{10}}{6{\cdot}4\times10^{14}}=5{\cdot}8\times10^{-5}\ \text{gm}=58\ \mu\,\text{gm}$$

CORRECT RESPONSE: $5{\cdot}8\ \mu$ gm of pure Ca^{45} will give 1 Ci of activity

STATEMENTS	CORRECT RESPONSE
100. Calculate the quantity of P^{32} which will give 100 mCi (milli-Curie) of radioactivity ; half life of the radionuclide is 14·3 days.	0·35 gm
101. An average human has about 150 gm of potassium in his body. Of this 0·012% is radioactive K^{40} which is natural. Calculate (the order only) the radioactivity present in a human body. Half life of the nuclide is $1{\cdot}25\times10^{9}$ years.	10^{-9} Ci (1 nano-Curie)

STATEMENTS	CORRECT RESPONSE
102. Like half life, physicists use another expression known as mean life to measure radioactive disintegration. It is obtained by adding together the whole lives of all the atoms concerned and dividing the sum by the total number of atom. Mean life stands for the average life expectancy of the atoms of a radioactive species. Calculations show that the mean life is equal to the reciprocal of the disintegration constant, λ. Mean life $=\frac{1}{\lambda}$. Recall that $\lambda=\frac{0{\cdot}693}{t_{\frac{1}{2}}}$. Hence, mean life= —— (in terms of half life).	$1{\cdot}44\ t_{\frac{1}{2}}$
103. Mean life $=1{\cdot}44\ t_{\frac{1}{2}}$. Half life and mean life (are/are not) proportional quantities. One gram of radium (226) emits $3{\cdot}7\times10^{10}$ particles per sec. Compute the average life of an atom of the nuclide.	are; $\bar{t}=\frac{N}{dN/dt}=\frac{6{\cdot}022\times10^{23}/226}{3{\cdot}7\times10^{10}}$ secs $=2284$ years
104. Mean life of Ra^{226} is 2284 years. This suggests that on the average each atom in an assembly lives without suffering any disintegration for —— years. Half life of Ra^{226} is —— years.	2284 1587

Note :

1. Which of the following are true ?
   (i) From atoms of low atomic numbers the release of α-particles is uncommon.
   (ii) Average binding energy per nucleon for stable atoms is about 8 MeV.
   (iii) Alpha particles are nothing but hydrogen nuclei.
   (iv) β-emission from the nucleus of an atom decreases its atomic number by 1.
   (v) α-emission from the nucleus of an atom decreases its mass number by 1 and atomic number by 1.
   (vi) Binding energy of the nucleus of an atom is the energy that is required to break the nucleus into its constituent particles.

STATEMENTS	CORRECT RESPONSE
(vii) Electrons in an atom accounts for all its negative charges.	
(viii) γ-rays are energetic photons having rest mass zero.	(i) ; (ii) ; (vi) ; (vii) ; (viii)
2. (i) Compute the mass equivalent energy of 1 a.m.u.	931·4 MeV
(ii) Compute the binding energy per nucleon of the C^{12} nucleus.	7·68 MeV
(iii) State whether true :	
(a) Binding energies of D^2 and He^3 are low.	
(b) Neutron-proton ratio is more than 1·5 in the nuclei of both U^{238} and U^{235} nuclides. They are unstable.	
(c) The curve obtained by plotting binding energy per nucleon as a function of mass number reveals a lot about the nuclear stability of atoms.	(a) ; (b) ; (c)
3. Half life of the artificially prepared radionuclide I^{131} used in studying the thyroid activity in patient, is about 8 days. If a patient is given a dose of 0·1 mCi, what activity will he retain even after a 32-day month ? Assume that no iodine is excreted during this period.	6·25 μ Ci
4. Radioactivity is measured in the unit of curie. One curie of activity is equal to $3{\cdot}7\times10^{10}$ d.p.s. How many d.p.s. take place in 6·25 μ Ci of activity ?	$2{\cdot}3\times10^5$ d.p.s.

X

Artificial Transmutation

The fact that certain nuclei undergo spontaneous disintegration led physicists to speculate about the possibility of causing disintegration of ordinary stable nuclides. We have already learnt to calculate the binding energy of various nuclides. Binding energy is the energy required to break up the nucleus into its constituent particles. It appeared possible that if atoms were bombarded with sufficiently energetic particles, one of the latter might penetrate into the nucleus and cause disruption, resulting finally in the formation of a new nucleus.

In 1919 Rutherford reported the first ever transmutation of one atom into another —— a fulfilment of the Alchemist's dream. He bombarded nitrogen with swift α-particles from a natural radioactive source and transformed the former into an isotope of oxygen, releasing swift protons in the process.

STATEMENTS	CORRECT RESPONSE
1. In the last chapter we have learned that like chemical equations nuclear equations can explain nuclear reactions. The nitrogen used by Rutherford as the bombarding target has the symbol $_7N^{14}$. Write down Rutherford's equation for this particular reaction.	$_2He^4 + {}_7N^{14} \rightarrow {}_8O^{17} + {}_1H^1$
2. In a nuclear reaction representing nuclear transmutation (or rearrangement), the sum of the mass numbers of the reacting particles (must be equal/need not necessarily be equal/sometimes equal) to the sum of the mass numbers of the product particles. This condition is also valid in the case of atomic numbers of the reacting particles. Can you verify the truth of this principle in the above reaction given in Item 1 ?	must be equal

Nitroflen nucleus + alpha particle = Proton + Oxygen nucleus

Mass number : $14+4=18$; $=1+17=18$.

Atomic number : $7+2=9$; $1+ 8= 9$

The stated principle is valid here.

STATEMENTS	CORRECT RESPONSE
3. Intensive investigation carried out into the nature of the products led scientists to introduce the formation of a very short-lived nucleus ; they called it 'compound nucleus'. Compound nucleus is formed when the nitrogen nucleus (captures/emits) an alpha-particle.	captures
Compound nucleus (preceeds/succeeds) the formation of product particles,	preceeds
In case of Rutherford's experiment, mentioned in Item 1, the compound nucleus must have had mass number —— and atomic number ——.	18 ; 9
We can identify the nucleus as ——.	$_9F^{18}$
4. Nuclear equation can successfully predict the formation of the product nucleus if the nature of the emitted particle is known. Transmutation of the sodium nucleus by alpha particle of requisite energy from a radioactive source may be represented by the equation : $_{11}Na^{23}+{}_2He^4 \rightarrow [{}_{13}Al^{27}] \rightarrow {}_{12}Mg^{26}+{}_1H^1$	
The compound nucleus formed is the nucleus of ——.	Aluminium
The product nucleus formed is that of ——.	Magnesium
$_1H^1$ represents the ——.	proton
5. Consult the periodic table in table 4 frequently. Complete the following (chemical/nuclear) equation and identify the products :	nuclear
$_5B^{10}+{}_2He^4 \rightarrow [\cdots\cdots] \rightarrow \cdots + {}_1H^1$	$[{}_7N^{14}]$ $_6C^{13}$
6. Complete the following equation and identify the products : $_{16}S^{32}+{}_2He^4 \rightarrow [\cdots\cdots] \rightarrow \cdots\cdots + {}_1H^1$	$[{}_{18}Al^{36}]$ $_{17}Cl^{35}$
7. In each of the Items numbering 1 to 6 above, the charges of the product nucleus increases by ——.	one
The mass (increases/decreases) by —— unit(s).	increases ; three
The alpha-proton reaction may, therefore, be written as : $_ZX^A+{}_2He^4 \rightarrow [\cdots\cdots] \rightarrow \cdots\cdots + {}_1H^1$	$[{}_{Z+2}C_n{}^{A+4}]$; $_{Z+1}Y^{A+3}$
8. In 1935 W. Bothe in Germany devised a simple scheme to describe the alpha proton (α-p) reaction. Since each chemical symbol is associated with a specific atomic number, the nuclear reaction described in Item 7 could be written as :	

$$X^A(\alpha, p)\,Y^{A+3},$$

where X^A is the target nucleus which interacts with an alpha particle (α), referred to as the incident particle orprojectile ; a proton (p) is ejected and Y^{A+3}, which remains, is the product (also called recoil from the point of view of collision dynamics) nucleus.

STATEMENTS	CORRECT RESPONSE
Following this scheme write down the complete equation for the reaction : K^{39} (α, p) Ca^{42}	: $_{19}K^{39}+{}_{2}He^{4}\rightarrow[_{21}Se^{43}]\rightarrow{}_{20}Ca^{42}+{}_{1}H^{1}$
9. The capture of an alpha-particle by a nucleus does not always result in the emission of a proton by the compound nucleus. In the classical experiment of Chadwick, which led him to discover the existence of neutron, a subatomic particle of mass number —— having —— charge, was ejected. The ejected particle was represented by the symbol ——. In this experiment beryllium, $_{4}Be^{9}$ was bombarded by α-particles. Write down the complete scheme of the reaction and then use the Bothe formula to represent the same.	one no $_{0}n^{1}$: $_{4}Be^{9}+{}_{2}He^{4}\rightarrow[_{6}C^{13}]\rightarrow{}_{6}C^{12}+{}_{0}n^{1}$; Be^{9} (α, n) C^{12}
10. When the boron nuclide, $_{5}B^{11}$ is bombarded by α-particles of requisite energy, the following reaction takes place : $_{5}B^{11}+{}_{2}He^{4}\rightarrow[\cdots\cdots]\rightarrow\cdots\cdots\cdots+{}_{0}n^{1}$ Write down the Bothe formula.	$[_{7}N^{15}]\rightarrow{}_{7}N^{14}$ $B^{11}(\alpha, n)\,N^{14}$
11. Once the particle accelerators were developed, the progress in the field of artificial transmutation became phenomenal. Particle accelerators are highly efficient machines, costly through, for producing high energy charged particles like protons, α-particles, deutrons and other light atomic nuclei. Cyclotron is a —— ——. It can accelerate (charged/uncharged) particles to MeV range of energy. The nuclide $_{3}Li^{7}$ when bombared by sufficiently energetic proton from a cyclotron, produces two α-particles. Write down the nuclear equation and also the Bothe formula for the reaction.	particle accelerator charged $_{3}Li^{7}+{}_{1}H^{1}\rightarrow[_{4}Be^{8}]\rightarrow{}_{2}He^{4}+{}_{2}He^{4}$, Li^{7} (p, α) He^{4}
12. The 'Dee's of the cyclotron are usually made of copper. When protons are accelerated inside the machine, some of them hit the copper 'Dee's resulting in transmutation of the copper isotope, Cu^{65}. Write down the nuclear equation as well as the Bothe formula to describe the reaction.	: $_{29}Cu^{65}+{}_{1}H^{1}\rightarrow[_{30}Zn^{66}]\rightarrow{}_{30}Zn^{65}+{}_{0}n^{1}$; $Cu^{65}(p, n)Zn^{65}$

STATEMENTS	CORRECT RESPONSE
13. Physicists use the symbol d to represent $_1H^2$ (deutron or heavy hydrogen). Describe the complete reaction represented by the formulae $O^{16}(d, \alpha)\ N^{14}$; $P^{31}\ (d, p)\ P^{32}$; $H^1(n, \gamma)\ H^2$.	: $_8O^{16} + {_1H^2} \rightarrow [_9F^{18}] \rightarrow {_7N^{14}} + {_2He^4}$ $_{15}P^{31} + {_1H^2} \rightarrow [_{16}S^{33}] \rightarrow {_{15}P^{32}} + {_1H^1}$ $_1H^1 + {_0n^1} \rightarrow [_1H^2] \rightarrow {_1H^2} + \gamma$
14. γ-rays being electromagnetic energy its emission (does/does not) affect the mass or charge of the nucleus.	does not
15. Atomic nuclei can also be disintegrated by bombarding them with high energy photons ; the process is known as photo-disintegration. Since photon has —— rest mass, it can only supply its energy in a nuclear reaction. This energy must be greater than the binding energy of the target nucleus. Write down the nuclear equation and also the Bothe formula for the photo-disintegration of deutron when neutron is one of the product particles.	zero : $_1H^2 + \gamma \rightarrow [_1H^2] \rightarrow {_1H^1} + {_0n^1}$ $H^2(\gamma, n)H^1$
16. Recall your idea about binding energy. The binding energy of a neutron in beryllium of mass no. 9 is low. γ-radiation which can cause photo-disintegration of the nuclide is (greater/less) than its binding energy. The Bothe formula of this reaction is	greater $Be^9\ (\gamma, n)\ Be^8$
17. So far we have discussed nuclear reactions from the point of view of rearrangement of nucleons, resembling ordinary chemical reactions. One of the limitations of the chemical equation is that it does not say anything regarding energy changes accompanying (atomic/nucleonic) redistribution. Chemical equations (are/are not) complete. Recall that the energy involved in a chemical reaction is (a few eV/of the order of keV/of the order of MeV.)	atomic are not a few eV
The overall energy liberated or taken up in a nuclear reaction is called 'nuclear reaction energy' and is generally represented by the symbol Q. Q of a nuclear reaction is of the order of (1/100/1000000) eV.	1000000
18. In a nuclear reaction Q is positive if there is (liberation/absorption) of energy ; Q is negative if there is (liberation/absorption) of energy.	liberation absorption

STATEMENTS	CORRECT RESPONSE
19. Recall Einstein's mass-energy equation. The nuclear reaction energy must be exactly balanced by the change of mass associated with the reaction. If Q is positive the total mass of the products must be (more/less) than that of the interacting nuclei. The balance mass is liberated in the form of energy. The liberated energy provides the necessary KE to the product particles and/or appears as γ-photon of definite frequency.	less
20. If Q is negative, the nuclear reaction is accompanied by (liberation/absorption) of energy. The total mass of the product particles must be (less/more) than that of the interacting nuclei.	absorption; more
21. Recall item 11. The nuclear reaction formula is $Li^7\ (p, \alpha)He^4$. The masses of the interacting particles as well as of the product particles are available from standard table :	

Interacting particles :		Product particles :	
Li^7	7·0160 a.m.u.	He^4	4·0026 a.m.u.
H^1	1·0078 a.m.u.	He^4	4·0026 a,m.u.
	8·0238 a.m.u.		8·0052 a.m.u.

STATEMENTS	CORRECT RESPONSE
The mass difference = 8·0052 − 8·0238 = −0·0186 a.m.u. The nuclear reaction under consideration is, therefore, accompanied by a (loss/gain) of 0·0186 a.m.u. Hence, Q of the reaction is (positive/negative). Compute the energy equivalent of this mass.	loss; positive; 17·3 MeV
22. The nuclear reaction $Li^7\ (p, \alpha)He^4$ is accompanied by —— of 17·3 MeV energy. Experimental determination of the kinetic energy of the product particles indicate that Q for the reaction is about 17·2 MeV. The agreement between the theoretical calculation and experimental result is (very good/not so good/unsatisfactory).	release; very good
23. Interacting particles and product particles (see below).	

Interacting particles :		Product particles :	
N^{14}	14·0030 a.m.u.	O^{17}	16·9991 a.m.u.
He^4	4·0026 a.m.u.	H^1	1·0078 a.m.u.
Total :	18·0056 a.m.u.		18·0069 a.m.u.
Difference :	0·0013 a.m.u.		

STATEMENTS	CORRECT RESPONSE
The reaction —— (complete) is accompanied by an increase in the mass of the product particles. Q of the reaction is —— MeV. It is (positive/negative). This	$N^{14}(\alpha, p)O^{17}$; 1·21 ; negative

STATEMENTS	CORRECT RESPONSE
is a case of (absorption/liberation) of energy in a nuclear reaction.	absorption
24. Refer to reaction in item 23. The nuclear reaction described (can/cannot) take place if 1·21 MeV of energy is not supplied from outside. Q of a nuclear reaction gives us (much/little) insight into the mechanism of reaction.	cannot much
25. Complete the reactions listed below and write down their nuclear equations : (i) $O^{16}(d, n)\cdots$ (ii) $H^1(n, \gamma)\cdots$ (iii) $Be^9(p, \alpha)\cdots$	
	(i) F^{17} ; (ii) H^2 ; (iii) Li^6 (i) ${}_8O^{16} + {}_1H^2 \rightarrow [{}_9F^{18}] \rightarrow {}_9F^{17} + {}_0n^1$ (ii) $H^1 + {}_0n^1 \rightarrow [{}_1H^2] \rightarrow {}_1H^2 + \gamma$ (iii) ${}_4Be^9 + {}_1H^1 \rightarrow [{}_5B^{10}] \rightarrow {}_3Li^6 + {}_2He^4$
26. Compute the Q value in MeV in each of the above reactions in item 25. Given, Mass of $O^{16} = 15·9942$ a.m.u. … … $H^1 = 1·0078$ a.m.u. … … $Be^9 = 9·0122$ a.m.u. Recall that mass of a proton = 1·00728 a.m.u. … … neutron = 1·00876 a.m.u. … an electron = 0·00055 a.m.u.	− 1·631 MeV 2·230 MeV 2·133 MeV
27. So far in this chapter we have learned how did the artificial transmutation come about, how to write down an expected nuclear equation and then to compute its Q value. The reader should have noticed by now that none of the end products of the reactions discussed so far is unstable. There is no justification, however, to presume that product nuclides should be stable. As early as in 1934, Joliot-Curie and her husband first noticed the production of artificial radioactivity produced by nuclear transmutation. In case of artificial transmutation of nuclides by bombarding them with energetic particles, the product nuclides (must/should /need not necessarily) be stable.	need not necessarily
28. Joliot-Curie and her husband were trying to study the nuclear reaction Al^{27} (α, n) P^{30}. The product ${}_{15}P^{30}$ is an isotope of phosphorus and is not found in nature. It is (likely/unlikely) to be unstable and hence ——.	likely ; radioactive

STATEMENTS	CORRECT RESPONSE
29. P^{30} is a radioactive isotope of phosphorus. It decays by emitting positive electron, called positron, following the process : $${}_{15}P^{30} \rightarrow {}_{1}e^{0} + {}_{14}Si^{30}$$ The final product is an isotope of ——; it is a naturally occurring isotope of the element and is stable.	silicon
30. The positron has the same mass as that of the electron ; its charge is positive. When the nucleus emits a positron, the new nucleus contains one (more/less) proton. The positron is a short-lived particle and can travel only a small distance before it is slowed down. It immediately interacts with a free electron there (available in plenty in nature). The interaction causes the annihilation of both the particles with the release of γ-rays. Except in a few special cases, the energy of the γ-rays so released is always the same. Recall that the mass of the electron is 0·00055 a.m.u ; the mass of the positron is —— a.m.u. The total energy released in the annihilation of an electron positron pair is —— MeV (calculate). Ordinarily, a pair of γ-photons carry away this energy, moving in opposite directions from the point of annihilation, and sharing it equally between themselves.	less 0·00055 1·02
Nucleus which disintegrates by the emission of positron is said to undergo positive beta (β^+) decay. A beam of positrons emitted from the nuclei of an element is called positive beta (β^+) rays. Existence of positron emission can be experimentally observed by detecting γ rays of energy —— MeV near the specimen.	0·51
31. Artificial radioactivity is no way confined to decay by positron emission only. The equation of Item 29 has been cited for its historical importance. To-date well over a thousand different radioactive isotopes have been produced by using various nuclear reactions. In addition, the elements of atomic numbers 43 (named technetium from technetos or artificial) and 61 (named promethium from prometheus), which do not exist in nature, have been artificially produced. Several elements heavier than uranium (called transuranic elements), which might have had existed once in nature but have decayed completely by now, have also been	

STATEMENTS	CORRECT RESPONSE
produced in the laboratory. Plutonium (Pu) is an artificially produced element of atomic number 94. Its position in the periodic table is (above/below) uranium.	above
It (is/is not) a transuranic element. It (does/does not) occur in nature.	is ; does not
$_{94}Pu$ (is/is not) radioactive.	is
32. Let us recall. Half-life is a characteristic property of a particular nuclide. Half-life is (independent of /dependent on) the physical condition or state of chemical combination of the nuclide.	independent of
All artificially produced nuclides (have/do not have) definite half-lives.	have
33. Al^{27} (n, α) Na^{24} is the Bothe formula for the nuclear reaction $\cdots\cdots + {}_0n^1 \rightarrow \cdots\cdots + {}_2He^4$ (complete).	$_{13}Al^{27}$; $_{11}Na^{24}$
Na^{24} is an unstable unclide of sodium and is ——.	radioactive
Its half-life is 15 hours. Given 10 gm of this isotope how much of it will be there after 30 hours?	2·5 gm
Refer to Fig. 9.2. There are (more/less) neutrons in the nucleus of Na^{24} than protons.	more
Its position should lie (above /below) the curve.	above
34. Excess of neutrons in the nucleus of the above isotope of sodium is (likely/unlikely) to be the reason of its instability.	likely
It can become stable by emitting α-rays, β^--rays or β^+-rays. Refer to Item 82 in Chapter VIII. Na^{24} is (likely/unlikely) to emit α-rays.	unlikely
Energy required for positron emission is not available in its decay. Hence decay by beta-emission, called β^--decay, is the only permissible process for the radionuclide. Emission of energetic γ-rays, which leave both the charge and mass of the nucleus uneffected, is also possible.	
Recall that in negative beta-emission the mass of the nucleus (decreases by 1/increases by 1/remains unchanged);	remains unchanged
the atomic no., representing the no., of charges in the nucleus, (decreases by 1/increases by 1/ remains unchanged).	increases by 1
Write down the decay equation of $_{11}Na^{24}$.	$_{11}Na^{24} \rightarrow {}_{12}Mg^{24} + {}_{-1}e^0 + \gamma$-rays

35. In an atomic reactor, which uses enriched uranium as fuel, the following nuclear reactions, apart from the fission process, take place :

$$_{92}U^{238} + {}_0n^1 \rightarrow {}_{92}U^{239} + \gamma\text{-rays.}$$

U-239 is radioactive and has a half-life of 23 minutes.

$$_{92}U^{239} \rightarrow {}_{93}Np^{239} + {}_{-1}e^0$$

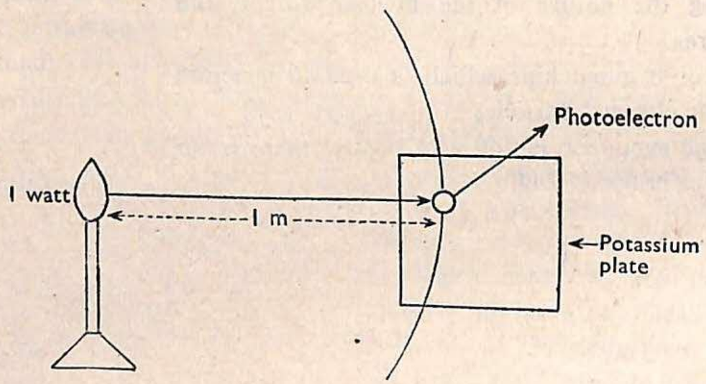
STATEMENTS	CORRECT RESPONSE
Np-239 is radioactive and has a half-life of 2·3 days. $_{93}Np^{239} \rightarrow {}_{94}Pu^{239} + {}_{-1}e^0$. Pu-239 is radioactive and has a long half-life of about 25000 years. It can undergo fission by slow neutrons. Hence, it is widely used in reactor industry. Can you describe the above reactions, which takes place inside a reactor, in words ?	Nuclei of U-238 capture neutrons available in abundance inside an atomic reactor. This results in the formation of a highly unstable isotope of uranium U-239 along with release of energetic γ-rays. U-239 undergoes negative beta (β^-) decay to form an unstable isotope of naptunium, Np-239. This also decays rather quickly by emitting β^--rays to an isotope of the element plutonium, $_{94}Pu^{239}$, which has a very long half-life.

NOTE :

1. Pick out the correct statements :
   (i) Artificial transmutation of an element results in the formation of only stable isotope of the same element.
   (ii) Joliot-Curie and her husband were the first to report artificial transmutation of an element.
   (iii) Transmutation of an element is possible only when the energy of the incident particle, called projectile, is more than the binding energy of its atomic nucleus.
   (iv) Artificial nucildes decay only by emitting β^+-rays.
   (v) Positron emission, in case of positive (β^+) decay, is possible only when there are more protons than there should be (for stability reasons) in a nucleus.
   (vi) In many cases of radioactive decays, γ-emissions accompany α-emissions and β-emissions — (iii) ; (v) ; (vi)
2. Which of the following statements are wrong ?
   (i) In an atomic reactor, the fission process is the source of power generation.
   (ii) In an atomic reactor, production of Pu-239 is the direct result of the fission process.

STATEMENTS	CORRECT RESPONSE
(iii) Nuclear reaction equations and Q-values in case of artificial transmutations do not help us in understanding the nature of the nuclear forces and structures.	
(iv) Cyclotron is a machine which is used to generate energetic charged particles.	
(v) Although cyclotron is not very costly, there is no cyclotron in use in India.	(ii) ; (iii) ; (v)

Panel 1.



PROBLEM

A potassium plate is placed 1 m from a feeble light source of power 1 watt (=1 J/s). Assume that an ejected photoelectron may collect its energy from a circular area of the plate whose radius r is, say, one atomic diameter : $r \approx 10^{-10}$ m. The energy required to remove one electron from the potassium surface is about $3{\cdot}4 \times 10^{-19}$ J. How long would it take for such a target to absorb this much of energy from the light source? Assume that the light energy is spread uniformly over the wave front.

SOLUTION

Target area is $\pi r^2 = \pi \times 10^{-20}$ m^2

Area of a sphere of radius 1 m centred on the source $= 4\pi$ m^2

If the source radiates uniformly then the rate of fall of energy on the target is given by :

$$R = 1 \text{ J/s} \times \frac{\pi \times 10^{-20}}{4\pi} = 2{\cdot}5 \times 10^{-21} \text{ J/s}$$

Assuming all the power absorbed, we may calculate the time required for the electron to acquire enough energy to escape. We find :

$$t = \frac{3{\cdot}4 \times 10^{-19}}{2{\cdot}5 \times 10^{-21}} = 1{\cdot}4 \times 10^{2} \text{ s} \approx 2 \text{ min}$$

We can modify the above calculation to reduce the time, t, by assuming a larger effective target area. The most favourable assumption that energy is transferred by a resonance process from light wave to electron leads to a target area of λ^2, where λ is the wavelength of light. For ultraviolet light of wavelength $\lambda = 100$ Å, $t \approx 10^{-2}$ s. This time lag between the incidence of light on the target and emission of photoelectron is well within our ability to measure experimentally. No time lag, however, has ever been detected under any circumstances. No wonder that the early experimentors set an upper limit of one nano-second on any such possible delay !

Table 1

Metal	*Work function*	*Threshold Wavelength*
	(eV)	Å
Lithium	2·28	5440
Sodium	2·46	5040
Potassium	2·24	5530
Rubidium	2·18	5680
Caesium (Cesium)	1·91	6490
Calcium	2·70	4590
Barium	2·51	4940

In electronics and nuclear physics it is found convenient to express energy in terms of electron volt (eV). It measures the energy possessed by an electron after it has passed through a potential difference of one volt ; $1 \text{ eV} = 1{\cdot}6 \times 10^{-19}$ joule of energy.

Table 2

ENERGY (PER MOLECULE) INVOLVED IN SOME TYPICAL CHEMICAL AND PHYSICAL INTERACTIONS

Type of Interaction	*Energy*
Decomposition of water into hydrogen and oxygen	2 eV
Combustion of carbon	4 eV
Combustion of petrol	40 eV
Decomposition of TNT	30 eV
Removal of both the electrons from helium atom	80 eV
Ionization of hydrogen	14 eV
Emission of photoelectrons from sodium	5 eV

Table 3

Atomic Masses of Some of the Stable Nuclides

Nuclide	*Number of protons, Z*	*Number of neutrons A—Z*	*Mass* a.m.u.
n^1	0	1	1·008665
H^1	1	0	1·007825
H^2	1	1	2·014096
He^4	2	2	4·002600
Li^7	3	4	7·015992
Be^9	4	5	9·012176
B^{11}	5	6	11·009295
C^{12}	6	6	12·000000
C^{13}	6	7	13·003341
N^{14}	7	7	14·003066
O^{16}	8	8	15·994915
O^{17}	8	9	16·999124
O^{18}	8	10	17·999118
F^{19}	9	10	18·998407
Ne^{20}	10	10	19·992440
Al^{27}	13	14	26·981502
Si^{28}	14	14	27·976883
P^{31}	15	16	30·973716
S^{32}	16	16	31·972026
Cl^{35}	17	18	34·968789
Cl^{37}	17	20	36·965905
A^{40}	18	22	39·962383
Ca^{40}	20	20	39·962625
Fe^{56}	26	30	55·934940
Cu^{63}	29	34	62·929601
As^{75}	33	42	74·921692
Sr^{88}	38	50	87·905734
Mo^{98}	42	56	97·366287
Sn^{116}	50	66	115·902000
Sn^{120}	50	70	119·902210
Xe^{130}	54	76	129·903510
Xe^{136}	54	82	135·907210
Nd^{150}	60	90	149·920830
Hf^{176}	72	104	175·940560
W^{184}	74	110	183·949820
Au^{197}	79	118	196·965380
Pb^{206}	82	124	205·972420
Th^{232}	90	142	232·036030
U^{238}	92	146	238·048620

The data given are based on C^{12}=12·000000 a.m.u.

Table 4

Periodic Table

Atomic Number Z	*Element*	*Symbol*	*Atomic Number Z*	*Element*	*Symbol*
1	Hydrogen	H	47	Silver	Ag
2	Helium	He	48	Cadmium	Cd
3	Lithium	Li	49	Indium	In
4	Beryllium	Be	50	Tin	Sn
5	Boron	B	51	Antimony	Sb
6	Carbon	C	52	Tellurium	Te
7	Nitrogen	N	53	Iodine	I
8	Oxygen	O	54	Xenon	Xe
9	Fluorine	F	55	Cesium	Cs
10	Neon	Ne	56	Barium	Ba
11	Sodium	Na	57	Lanthanum	La
12	Magnesium	Mg	58	Cerium	Ce
13	Aluminium	Al	59	Praseodymium	Pr
14	Silicon	Si	60	Neodymium	Nd
15	Phosphorus	P	61	†Promethium	Pm
16	Sulphur	S	62	Samarium	Sm
17	Chlorine	Cl	63	Europium	Eu
18	Argon	A	64	Gadolinium	Gd
19	Potassium	K	65	Terbium	Tb
20	Calcium	Ca	66	Dysprosium	Dy
21	Scandium	Sc	67	Holmium	Ho
22	Titanium	Ti	68	Erbium	Er
23	Vanadium	V	69	Thulium	Tm
24	Chromium	Cr	70	Ytterbium	Yb
25	Manganese	Mn	71	Lutetium	Lu
26	Iron	Fe	72	Hafnium	Hf
27	Cobalt	Co	73	Tantalum	Ta
28	Nickel	Ni	74	Tungsten	W
29	Copper	Cu	75	Rhenium	Re
30	Zinc	Zn	76	Osmium	Os
31	Gallium	Ga	77	Iridium	Ir
32	Germanium	Ge	78	Platinum	Pt
33	Arsenic	As	79	Gold	Au
34	Selenium	Se	80	Mercury	Hg
35	Bromine	Br	81	Thallium	Tl
36	Krypton	Kr	82	Lead	Pb
37	Rubidium	Rb	*83	Bismuth	Bi
38	Strontium	Sr	*84	Polonium	Po
39	Yttrium	Y	*85	Astatine	At
40	Zirconium	Zr	*86	Radon	Rn
41	Niobium	Nb	*87	Francium	Fr
42	Molybdenum	Mo	*88	Radium	Ra
43	†Technetium	Tc	*89	Actinium	Ac
44	Ruthenium	Ru	*90	Thorium	Th
45	Rhodium	Rh	*91	Protactinium	Pa
46	Palladium	Pd	*92	Uranium	U

† Elements not found in nature
* Radioactive elements.

A PROGRAMMED COURSE IN MODERN PHYSICS

Students find difficulty in accepting new ideas of the scientific revolution, commencing from 1985 onwards, because traditional presentation of physics at school and college levels gives birth to wrong notions regarding the continuity between classical and modern physics ; and secondly, because of the teacher's difficulties in introducing new concepts to familiar ones, and ultimately, total failure to find analogies which could help the students grasp the ideas.

To overcome these difficulties the author has designed a set of programmed instructions for each topic, representing a modern concept, arranged in a sequence by which awareness should develop about interdependence of different concepts and also their link with the past.

Dr. Rajarshi Bhattacharjee, a teacher in science of long standing and repute has a brilliant academic career behind him. He did his M.Sc. in Physics from Gauhati University and also in Medical Physics from Aberdeen University and was graduated a doctorate in Bio-Physics from the Gauhati University. A member of the Indian Physics Association, Dr. Bhattacharjee has a number of research papers published in leading science journals in India and abroad. He has over 15 years' experience in teaching science at various levels, is at present the Deputy Director of the Pre-Examination Training Centre of the Gauhati University.

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